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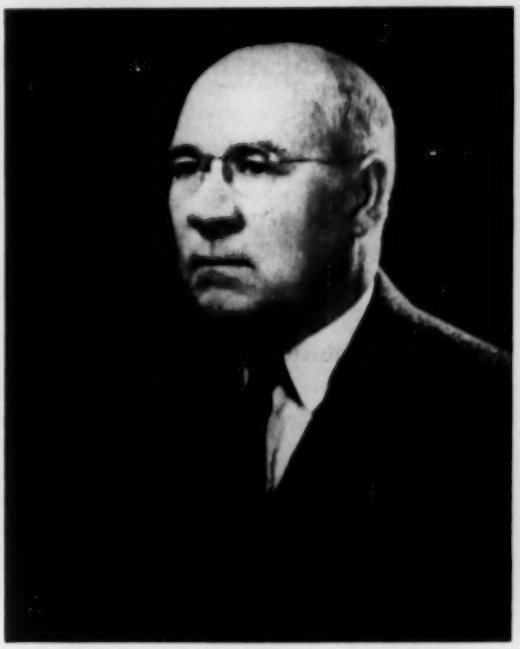
PRESIDENT'S MESSAGE



HIGHLIGHTS OF THE YEAR

By Howard P. Emerson

President of the American Institute of Industrial Engineers

Building on spade work of the past, this has been a year of solid, continuous growth.

New Members (Based on records for first 10 months of the year)

	May 19, 1956	March 19, 1957
Fellows	11	13
Senior members	1402	1771
Senior life members	0	1
Associate members	2398	3242
Total Voting Members	3811	5027
Student members	1360	1400
Affiliates	271	336

New Chapters

May 19, 1956 53 chapters
March 19, 1957 71 chapters

These 18 new chapters show a virility and professional interest in AIIE affairs which augurs well for the future of our organization. The new chapters are scattered throughout the country.

Chapter Visits

Sixteen chapters, including five of the new chapters, were visited by the President. Additional visits were made by other national officers and the Business Administrator. Two of the Vice-Presidents visited every one of the chapters in their regions. Two regions had special meetings of all chapter presidents. Others had business meetings at annual Regional Conferences.

Regional Meetings

Some of the regional conferences were of the caliber of past national meetings in terms of speakers and programs. Regional meetings were held, as follows:

Northeast	Regional Presidents Meeting Syracuse, New York	January, 1957
Southeast	Regional Conference Knoxville, Tennessee	February, 1957
Central	Regional Presidents Meeting Columbus, Ohio	January, 1957
Midwest	Regional Conference St. Louis, Mo.	March, 1957
Pacific Northwest	Seattle, Wash.	April, 1957
Pacific Southwest	San Diego, Calif.	April, 1957

Engineers Joint Council

AIIE participated this year as an associate member, being represented at Directors' meetings and the Annual Conference in New York in January, 1957. Through the Council, AIIE also acted as co-sponsor of the 1957 Nuclear Congress in Philadelphia in March.

The AIIE Executive Committee approved continued participation with other engineering groups in the 1958 Nuclear Congress on the basis of Industrial Engineering interest in nuclear economics, industrial uses of radioactive isotopes, utilization of valuable wastes, and safety procedures.

Board of Trustees

At its October, 1956, meeting the Board approved the budget for 1956-57 (October 1 to October 1); a revised organization for AIIE incorporating the new position of Vice-President; publication of a book; and an ad hoc committee for Government Operations to investigate the problem of definition and status of Industrial Engineering in the Civil Service and the Armed Forces. In January, 1957, the Board appointed Floyd Titler as Vice-President for the rest of the year to May 18. Other actions of the Board appear under respective reports below.

Executive Committee

An innovation was tried of having some of the monthly meetings of the Executive Committee outside of Columbus. One was held in New York in January to review plans for the 1957 Conference and Convention and a second in Knoxville, Tennessee, in February in connection with the Annual Southeast Regional Conference.

Executive Secretary

The January-February, 1957, issue of the Journal contained an article on the work of the Executive Secretary and Business Administrator. As the year ended, decision was reached on the choice of the first full time paid Executive Secretary. So much as been accomplished over the years by voluntary effort that it is reasonable to expect that this step will lift AIIE to a higher plateau of activity and accomplishment.

Treasurer

An Expense Planning procedure was set up during the year, with provision for review of the budget twice a year by the Board of Trustees.

Provision for a cash reserve recommended by the Treasurer was approved by the Board of Trustees.

PRESIDENTIAL COMMITTEES

Professional Relations Consistent, continuing activity over the years showed fruition in the relationships now enjoyed with the Engineers Joint Council. A joint meeting at the 1957 National AIIE Conference with ORSA (Operations Research Society of America) and TIMS (The Institute of Management Science) indicates a gradual expansion of AIIE relationships.

Organization Approval by the membership of a constitutional amendment adding a First Vice-President led to the reorganization described in the March-April, 1957, issue of the Journal. A new organization chart and manual were prepared with job descriptions for every job on the chart.

Publications-coordination AIIE is in the publishing business. After thorough review, approval was recommended for publication in book form of the research report on "Functions and Bases of Time Standards" by Harold O. Davidson. A foreword states that AIIE feels a responsibility to make available research studies to keep students and plant men informed, even though results may be preliminary or of specialized interest.

Long Range Planning The annual symposium to guide long range thinking about the profession was held this year at Purdue University. The new definition of Industrial Engineering developed in a previous symposium was carefully reviewed, re-approved, and its growing acceptance noted. Statements were developed explaining Industrial Engineering and its new definition to top-management, the worker, student, and man-on-the-street.

Special Surveys A survey was made of members of AIIE. Members of AIIE are relatively young; the largest group is in production doing methods and time study work; the next largest group is in top administration. Every industry classification in the census uses industrial engineers. Results of the survey will be published from time to time in the Journal.

Journal of Industrial Engineering During 1956, 55 articles were published to keep members up-to-date in a growing profession. Each issue now runs 10 pages larger than last year. The press run for each issue is now in excess of 8000 copies.

DIRECTORS

Programs A new manual was issued containing practical suggestions for running chapter programs, with ratings of speakers.

Chapter Expansion Eighteen new chapters had been added to March 19, 1957. The manual for organizing new chapters was expanded and re-issued.

Research Committees were set up covering major fields of Industrial Engineering interest. Their job is to keep abreast of developments in these fields and stimulate research in them. Harold Davidson's book was published as a research monograph. A proposal for time study films was reviewed.

Functional Committees MQC, the Membership Qualifications Committee, continued to be the hardest working committee in the organization. 1158 applications were reviewed in the first 10 months. As an extra assignment the committee made a report reviewing and making recommendations on the status of affiliates. The Executive Committee and Board of Trustees reaffirmed previous decision that affiliates, as in other engineering societies, though not voting members must pay their full share of dues. Associate members are subsidized for the first five years, because most of them are recent graduates with lower incomes, but this provision does not cover affiliates. A new committee on Opportunities Service was set up to act as a clearing house for jobs in the field of Industrial Engineering.

The committee on Resolutions and Awards assembled data on candidates for new Fellows of AIIE. New pins and plaques were chosen.

Membership With an increase in dues taking place in 1956 loss of membership was expected. The loss was less

than the 10 per cent attrition experienced annually by similar professional societies. Quotas for membership expansion were established.

National Meetings A new manual to help organize national and regional conferences and conventions was approved and issued during the year.

Public Relations Recommendations were made. Local chapters were contacted. A film of Industrial Engineering as a Career is in the development stage.

Student Chapters The policy to recognize student chapters as such only in institutions having accredited curricula or options in Industrial Engineering was re-examined by the Executive Committee and re-affirmed. On this basis one new chapter was added, at Iowa State College.

International Relations This committee has undertaken the formulation of an AIIE policy on International chapters and activities.

Terminology A committee to formulate and keep up to date definitions of Industrial Engineering terms was re-appointed.

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Incentive Wage Practice for Restricted Work

By Dr. John C. Scheib, Jr.

Assistant Professor, Production Management, University of California

Very often the published descriptive literature has approached the analysis of wage incentives as though the systems were to be applied only to productive efforts of men performing completely unrestricted manual work i.e. manual work unrestricted by the necessary accompaniment of machine or process. This is, of course, an unrealistic view in light of the present status of mechanization and automation in industry. Recognition of a distinction between restricted and unrestricted work is exceedingly important in view of the fact that provision of adequate potential incentive in the two situations requires very different basic approaches.

Basis for Incentive Compensation

The underlying basis for many traditional production wage incentives rests on the assumption that the average worker can perform his job in less time than is normally required for performance without special financial motivation. One very simple and straightforward basic method of providing incentive involves compensating the worker on the basis of the results he achieves relative to a standard of performance for the job.

This basic foundation for production wage incentives is sufficient only in unrestricted work. In process or machine restricted work, variation in the performance time is precluded by the nature of the operation. If it is desired to provide a financial incentive in such a production situation, by paying the employee on the basis of work performed as measured by standard time, it is necessary to give special consideration to the development of the "standard time."

Process restriction is not the only factor necessitating special consideration in the development of standard time. One convenient classification provides three categories:

1. Allowance for personal time.
2. Allowance for irregular occurrences.
3. Allowance for machine time.

All of these factors are of importance in protecting the existence and effectiveness of the common type of incentive which has been referred to above. Industrial engineers have generally recognized the necessity for the first two types of adjustment by incorporating personal, rest and delay allowances in their work measurement procedures. The problems involved are measurement problems.

The Problem of Work Restriction

The third factor, however, deals with the problem of work restriction, and handling of this factor shows lesser degree of uniformity. *The solution to this problem cannot be fulfilled with pure measurement techniques but must involve the basic design of the incentive structure.*

Equipped with an incentive program designed for unrestricted work situations, and faced with an application involving restriction, the practicing industrial engineer must follow one of three alternatives:

1. Ignore the effect of restriction and develop an unadjusted time standard.
2. Apply the basic incentive structure to the special situation by providing for development of a standard time which is adjusted to reflect the degree of restriction.
3. Develop a completely new incentive structure to give recognition to the unique characteristics of the work situation.

A survey of industrial practice, undertaken as part of a more extensive research project, indicates that formal policies of industrial organizations do incorporate each of the three stated alternatives. An analysis of a selected number of such formal policies, described by standard operating procedure manuals, gives an indication of the results to be expected from each alternative, and the variety of approaches to compensating for the restriction factor (as indicated in both 2 and 3).

This analysis has resulted in the classification of approaches into five categories:

I. Straight standard hour.
II. Standard hour with constant machine incentive allowance.
III. Standard hour with constant work incentive.
IV. Empirical consideration of work performance.
V. Empirical consideration of work performance and equipment performance.

In order to prevent misunderstanding, the following terms are defined for use in discussing the methodology of the five general approaches.

EXTERNAL = Standard time for unrestricted work performed outside (external to) the restricted portion of the work cycle.

INTERNAL = Standard time for work performed during (internal to) the restricted portion of the cycle.

IDLE = Enforced cyclical idle time when internal work is performed at normal pace.

INCENTIVE IDLE = Enforced cyclical idle time when internal work is performed at incentive pace.

MACHINE TIME = Constant time requirement for the machine or process restricted portion of the operation cycle.

PERFORMANCE STANDARD = Total standard time allowance for the operation.

TRUE WORK = Total standard time allowance for manual work content of the operation.

CYCLE TIME = Time requirement for one complete cycle of the operation.

ACTUAL = Actual elapsed time required for performance of one cycle in a work situation.

TRUE WORK INDEX = A measure of the efficiency of utilization of manual work.

EQUIPMENT INDEX = A measure of the efficiency of utilization of equipment.

EARNINGS INDEX = A measure of overall efficiency of an operation reflected in earnings.

Description of Industrial Practice

Using this terminology, brief description of the five types of incentive structures encountered can be attempted.

I—*Straight standard-hour.* Designating the use of all systems incorporating straight measurement of normal elapsed time in the development of the time standards. This would include "piece rate" systems, as well as that system commonly referred to as standard hour, in all situations where no formal consideration is given to the presence of work restriction in the standards development. Although there are many variations of terminology used in conjunction with this type of structure, a simple formula for development of the standard could be:

$$Performance\ Standard = External + Machine\ Time$$

The evaluation of performance could then be arrived at as:

$$Earnings\ Index = Performance\ Standard \div Actual.$$

II—*Standard-hour with constant machine incentive allowance.* Designating the use of all systems incorporating measurement of normal elapsed time in the development of the time standard, but differing from Type I in that the elapsed time values are adjusted in such manner as to incorporate an automatic bonus of constant percentage for restricted segments. Exemplary formulae for use in the development and application of this structure are:

$$Performance\ Standard = External + (f)\ Machine\ Time$$

$$Earnings\ Index = Performance\ Standard \div Actual\ Time.$$

III—*Standard-hour with constant work incentive.* Designating the use of all systems incorporating measurement of normal elapsed time in the development of the time standard, but differing from Type I in that elapsed time values are adjusted in such a manner that the degree of incentive potential during restricted work periods is directly dependent upon work load involved. Although the formula for determination of earnings for this type could be identical to that used in the first two types, the method and formula for development of the standard is basically different:

$$Performance\ Standard = External + Machine\ Time + (f)\ Internal$$

A more specific formula defining the function of internal work time is:

$$Performance\ Standard = External + Internal + [Machine\ Time - (Internal \div Incentive\ Pace)] = External + Internal + Incentive\ Idle.$$

IV—*Empirical consideration of work performance.* Designating plans which provide for empiric development of earnings by use of prepared tables, etc., which give primary consideration to manual work time involved. Such an incentive structure must be designed specifically for such restricted work situations, and empirically developed tables must reflect the degree of restriction.

Since this type does involve empirical development, the terminology is subject to great variation. Similarity in systems of this type results from the emphasis on manual efficiency using a measure of true work in performance standard development:

$$True\ Work = Internal + External$$

This true work standard is used in the determination of a true work index:

$$True\ Work\ Index = True\ Work \div Actual$$

The empirical effect is in determination of the earnings index using the true work index:

$$Earnings\ Index = (f)\ True\ Work\ Index$$

The function (f) is empirically developed to reflect the degree of restriction in the work.

V—*Empirical consideration of work performance and equipment performance.*

Designating plans which provide for empiric development of earnings through use of separate considerations of manual work efficiency and efficiency of machine utilization. Such an incentive structure requires "dual standards development" and is necessarily applicable only to restricted work situations whereby man is paced by machine or process. Such systems require development of separate "time standards" for manual work and for process requirements, application of these standards in actual work situations to determine efficiency indices for work and for equipment, and joint consideration of these separate indices to empirically determine an overall efficiency index for use in the calculation of earnings level.

Stated in terms of formulae, exemplary Type V structure could involve consideration of:

$$True\ Work = Internal + External$$

$$True\ Work\ Index = True\ Work \div Actual$$

Consideration of equipment performance is achieved by:

$$Cycle\ Time = Machine\ Time + (External \div Incentive\ Pace)$$ and $$Equipment\ Index = Cycle\ Time \div Actual$$

The empirical effect is in development of an overall performance index such that:

$$Earnings\ Index = (f)\ True\ Work\ Index + (f)\ Equipment\ Index$$

In actual practice this last functional relationship is usually pre-calculated and provided in tables.

Sufficiency of the Categorization

This listing certainly does not completely cover all of the many proposals in the history of wage incentives. At least three additional types could be included as variations of Types I through III to incorporate "gain-sharing". However, although "gain-sharing" is certainly an incentive characteristic meriting detailed consideration, it is a device introduced for reasons other than the solution of incentive problems created by work restriction. Its effect in this respect might be considered so minor as to justify non-consideration.

Although the categorization provided is admittedly incomplete, a large majority of current production wage incentives for direct labor applications are probably included. Type I fulfills the previously described alternative of "ignoring restriction," Types II and III each illustrate conformance with the second alternative of "adjusting the standards within the incentive structure," and Types IV and V conform to the third alternative of "completely new incentive structures."

By detailed analysis of selected incentive plans which conform to each of the above described "types," it is possible to make relatively objective and realistic evaluation of the practical sufficiency of each of the several types in achieving "incentive goals" with respect to restricted work situations. In order to accomplish such evaluation, however, there must be provided some uniform standards for comparison.

Criteria for Evaluation

From the millenium of publishments and recommendations on the subject of wage incentives, it is difficult to list and consider all of the large number of "requirements of good practice" which have been proposed. This may not be necessary in the present instance as many requirements can be satisfactorily fulfilled within any of the basic structures considered. The criteria can be limited to those most subject to violation in providing compensation for restricted work and enforced cyclical idle time. This should be sufficient for evaluation of the industrial practice described.

In accord with this approach there can probably be found some agreement that financial wage incentive programs should, among other things:

1. Be simple and understandable.
2. Make possible computation of earnings by the employee.
3. Provide sufficient reward attainable with reasonable effort.
4. Appear equitable in order that proper attitudes be fostered.

Actually these requirements can be divided into two basic criteria to be used in evaluation. One of these, indicated by the last two of the above requirements, involves the *results* of the development and application as reflected in earnings indices. Three guiding characteristics are involved: 1) provision of attainable differentials of adequate size, 2) provision of consistency of opportunity between applications, and 3) provision of potential attainments equitable in comparative considerations.

The other of the basic criteria is indicated by the first two requirements which deal with the lack of complexity in methodology and the ease of administrative computation. Evaluation on the basis of this criterion must be executed with complete awareness of the method of performance standard determination and of earnings index determination.

Analysis Procedure for the Evaluation

Although this second criterion might be satisfactorily considered by analysis of the general mechanics involved, the nature of the first criterion with respect to the *results* of application of the system can only be evaluated according to performance in work situations. Since there are at least two pertinent variable characteristics of such work situations, i.e. degree of restriction and proportion of idle time, several different types of work situations must be considered.

For purposes of the research summarized here, six different but related work situations or cases were considered.

Case I 100% unrestricted, no idle time involved.
Case II 50% unrestricted, 10% idle during cycle.
Case III 10% unrestricted, 10% idle during cycle.
Case IV 50% unrestricted, 50% idle during cycle.
Case V 10% unrestricted, 90% idle during cycle.
Case VI 0% unrestricted, no idle time involved.

The percentages listed are predicated on standard times established on the basis of elapsed times at normal performance. In order to develop standards for each of the incentive systems analyzed, specific time values were developed to conform to each case.

In order to apply these standards, it was also necessary

to arbitrarily assume levels of manual performance in the execution of the operations:

1. sub-normal level of 75%.
2. normal level of 100%.
3. expected level of 125%.
4. superior level of 150%.

These percentages were applied only to the times for manual work and were assumed to be consistent regardless of the degree of idleness in the operation.

Only the conclusions of the described investigative procedures, with respect to each of the general types of incentive systems, can be reported here. The details of the various computations for each specific system of incentive is included in the original research report listed in the references to this paper.

A Rating System for the Evaluation

This evaluation with respect to the first criterion, provision of sufficient attainable earnings which are consistent and equitable, makes use of a three-degree descriptive rating for each of the three facets involved: *satisfactory, doubtful, or unsatisfactory.*

This rating system is applied to the probable adequacy of earnings, under each type of incentive, in motivating maintenance of equipment performance. Such evaluation is dependent only upon provision of incentive at any level of manual performance. The same rating system is applied with respect to the probable *maintenance of the level of manual performance* which is contingent upon the provision of adequate reward at the expected level of performance, and also upon there being sufficient differential of reward between different levels. The third facet of the first criterion, to which the same rating system is applied, concerns the *consistency and equity of earnings* and depends, primarily, on the effect of increased idle time upon earnings potential.

The evaluation with respect to the second criterion involves rating two factors in each of two primary types of methodology: 1) methodology of standards development, and 2) methodology of earnings computation. The first factor considered with respect to each methodology is the *complexity of the mathematical computations* required. The rating scale for evaluation of this factor involves four degrees: *very simple, moderately simple, moderately difficult,* and *very difficult.* The rating applied is dependent upon the nature of the computations involved. The second factor concerns the *ease of explanation* (and justification) of the methodology and can be descriptively evaluated with a four degree rating scale: *straight-forward, slightly involved, moderately involved,* and *very involved.*

Description and Comparative Evaluation

A summarization of the descriptive evaluation is shown in Figure 1 for the five basic types of incentive structure. These ratings have been applied on the basis of performance in the cases described of actual incentive structures conforming to each of the several types.

TYPE I In Type I structures, the methodology involved can be considered relatively *very simple.* Computation of the performance standard involves only summing the measurable times for the various components of the job, and earnings computation (in terms of time) involves simply the summation of the work (measured in units of standard time) performed. The methodology can also be considered *straight-forward* since it can be justified on the basis of direct measurement of the work requirement in terms of time. This is in conformance with traditional modes with respect to remuneration for work.

A consideration of the adequacy of earnings provided by a Type I incentive structure does not provide so satisfactory an evaluation. Detailed analysis of earnings provided in different "cases" indicates that, except for un-

Type of System	Descriptive Rating of Incentive Structure with Regard to: Adequacy of Earnings for Maintenance of			Standards Development		Earnings Computation	
	Equipment Performance	Manual Labor Performance	Equitable Consistency	Mathematical Computations	Ease of Explanation	Mathematical Computations	Ease of Explanation
I	unsatisfactory	unsatisfactory	unsatisfactory	very simple	straight forward	very simple	straight forward
II	satisfactory	satisfactory	unsatisfactory	moderately simple	slightly involved	very simple	straight forward
III	satisfactory	satisfactory	satisfactory	moderately simple	slightly involved	very simple	straight forward
IV	unsatisfactory	unsatisfactory	satisfactory	very simple	slightly involved	moderately difficult	moderately involved
V	satisfactory	satisfactory	satisfactory	moderately difficult	very involved	very difficult	very involved

FIG. 1 Descriptive ratings of selected incentive structures with respect to performance when applied to restricted work operations.

restricted operations, job incumbents would be greatly restricted in earnings potential. For example, in 50% restricted jobs (Case II) a work pace of 125% is rewarded with only 110% earnings since only the time requirement for the unrestricted portion of the cycle could reflect increased pace of work. The sufficiency of such reward in motivating maintenance of performance with respect to either equipment or manual work is *doubtful*, and when reduced even further by increased restriction or enforced idleness it is almost certainly *unsatisfactory*.

The "equitable consistency" of earnings under Type I systems must also be considered *unsatisfactory* when applied to restricted cases, since the earnings level can provide potential for increased earnings based only on the unrestricted work rather than on the total manual work load.

TYPE II—The Type II structure involves a modification of the Type I, such that the standard time is modified to include a constant allowance, in addition to the standard time, for restricted portions of work cycles. The performance standard is not just a summation of elapsed time but includes a fixed proportion of restricted time as an incentive allowance. (The same result is achieved by expressing standard time at incentive pace rather than normal, and determining compensation relative to an incentive rather than a base pay level. Using this method, the "standard time" is a summation of the elapsed times.) The use of Type II structure has the result of modifying Type I structure to provide for handling controlled time as "incentive" time rather than standard time in the usual sense. This requires slightly increased complexity in the mathematics involved and reduces somewhat the straightforward simplicity of the standard-hour system. Neither effect is of a radical degree however.

The effect of this modification on the sufficiency of earnings potential provides distinct improvement over Type I incentive structure. The results of various applications of Type II systems from the standpoint of earnings indices indicates that the worker is provided greater incentive to avoid exerting a negative control on the restricted cycle. Through maintenance of the machine or process, increased effort expenditure results in sizeable increases in the earnings index—a characteristic not true of Type I applications.

A shortcoming of the Type II structure results from the fact that no consideration is given the extent of internal work load—i.e. the amount of manual work performed during the restricted portion of the cycle. For example, earnings potential is just as great for a Case IV (50% idle) operation as for a Case II (10% idle) operation. This characteristic results in an *unsatisfactory* rating with respect to the existence of inequities between various applications of the system.

TYPE III—Reference to Figure 1 indicates that Type III incentive structures merit the most satisfactory ratings with respect to general fulfillment of the criteria being considered. The structure for this type of system can be achieved in several ways, each of which is designed to fulfill the goal of providing equal incentive opportunity for all manual work regardless of whether it is external or internal to the restricting factor. Any attempt to fulfill such a goal with a structure which is simply a modification of Type I requires some degree of compromise, however. The compromise usually accepted necessitates the assumption of a desired performance level on which the development of standards is predicated. With this compromise, it is possible to develop time standards which will be equitable, consistent, and provide adequate incentive, but which will be completely correct in application only at the assumed level of performance.

Such a standard is developed by summing the times for all of the work elements required in performance of the task, and adding to this the idle time which will be encountered if the job is performed at some pre-established "incentive level" of performance. Such a system provides the job incumbent with full potential for incentive reward for performance of manual work at incentive pace. The incumbent is not penalized for cyclical enforced idle time since it will be automatically compensated for at the hourly rate. The system is only correct at the incentive level used in computation of the standard, however, since too much idle time would be included for work at less than incentive pace and too little for work at greater than incentive pace.

In spite of this shortcoming, the Type III structure provides *satisfactory* motivation to the incumbent for maintenance of equipment utilization, *satisfactory* incentive to maintain a desirable level of manual performance, and *satisfactory* maintenance of equitable relationships between different applications. It achieves this with *moderately simple* standards development computation and with relatively *very simple* earnings computations. Although the method of standards development is *slightly involved*, the method of earnings computation is very *straight-forward* and relatively easy to justify.

TYPE IV—Detailed analysis of the application of standards developed under Type IV structure indicates that, although the system results in logical consistency between applications from the standpoint of showing decreased earnings potential with increased idle time, it does not provide earnings differential between different levels of effort performance sufficient to motivate the higher levels of performance. It is also apparent that in cases with high percentages of idle time, sufficient financial incentive is not provided for motivation in overall performance.

The mathematical computations involved in the Type IV structure is *moderately involved* in an attempt to reflect adjustment to characteristics of the operations covered. The system involves use of predeveloped charts to incorporate allowances for enforced idle time into the earnings computation. These charts are used in conjunction with the "standard" for the operation—a standard which reflects only the "true work" content of the job. This requires that two index calculations be undertaken in the process of determining the earnings index—an index of

"true work" performance is modified by an empirically developed factor which reflects the degree of restriction.

Although the first index required in computation of earnings under the Type IV structure is very similar to the earnings index under the Type I system, this index must be used in computations involving a formula which is empirically developed and has no apparent logical justification from an equity standpoint. It is extremely doubtful that an average incumbent on an incentive job could either readily calculate his own earnings or justify the method of calculation.

TYPE V The Type V structure is the most elaborate encountered for provision of incentive payment for restricted production operations. Incentives of this type are not unusual, however, as this alternative has been chosen by an increasing number of organizations faced with increasing amounts of restriction in critical production operations.

This type of structure involves increased complexity with respect to both standards development and earnings computation. An attempt is made to give consideration to maintenance of equipment capabilities, as well as to performance of manual work, through development and application of dual standards. The first standard is a "true work" standard, i.e. a time measurement of manual work content. The second is a time standard for capacity machine performance and may be a simple summation of time requirements for the various components of the job at incentive level of performance. Although neither of the standards require complex development procedure, the fact that two standards are required makes for less meaning in the standards as true measures of the job requirements.

The procedure for earnings calculation with this system is the most complex of any considered since consideration must be given to two standards. This consideration necessitates calculation of three separate indices. The first two of these indices involve the use of the respective standards in conjunction with the actual time, and each set of calculations is very similar to that used in the (Type I) standard hour system for direct determination of earnings index. In the Type V system, however, these indices must be used in *very involved* mathematical procedure using formulae or prepared tables.

Because of the extreme complexity of standards development and earnings determination, Type V structure cannot be evaluated as fulfilling the second criterion. The earnings computation required must certainly be rated as *very difficult* and *very involved* since it is extremely doubtful that even the above-average job incumbent could readily calculate his earnings with reasonable expenditure of mental effort.

Reference to the rating chart indicates, however, that the *results* of application of this structure can provide generally satisfactory earnings as evaluated with the first criterion. The *very involved* computational procedure permits development of a desirable earnings pattern which can provide sufficient attainable earnings differential with consistency of opportunity and apparent equity in levels of compensation. The flexibility attained in use is the primary advantage of such an empirical development since it is possible to design an empiric structure which will cause a resultant earnings pattern predetermined as desirable. The complexity which may be necessary in achieving this goal may very well negate the results however.

Summary Conclusions

Study of information provided by the rating chart permits some summary conclusions with regard to the comparative adequacy of the several systems.

Type I methodology is uniformly unsatisfactory from the standpoint of provision of adequate incentive for restricted operations. The fact that an unsatisfactory system is very simple and straight-forward is no justification for application of the system.

At the expense of some simplicity, the Type II structure is capable of providing financial incentive with respect to both machine utilization and labor utilization in isolated applications. The method results in inconsistencies between jobs of varying characteristics, however, and would undoubtedly be productive of considerable worker dissatisfaction which could negate the incentive provided.

The most uniformly desirable ratings are earned by Type III methodology. Although some systems designed with this structure make use of pre-calculated tables, formulae, etc. causing the methodology to be undesirably involved, it is possible to simplify the mechanical aspects to cause them to be satisfactory. With only limited exceptions, the financial incentive provided is very satisfactory from the viewpoints used in this analysis. Where it can be satisfactorily applied, the Type III method of providing production wage incentive can result in almost complete adequacy.

The Type IV classification does not merit detailed discussion in a consideration of satisfactory methods of providing financial production incentive to restricted operations. The increased complexity of the methodology is difficult to justify by the generally unsatisfactory results in incentive provided.

The ratings with respect to adequacy of earnings provided by Type V systems indicate that this methodology is capable of providing satisfactory levels of earnings for provision of monetary incentives. However, this is achieved only through introduction of highly complex developmental procedures which are probably logically unjustifiable to the employee. This characteristic, combined with involved computational procedures in administration, causes Type V structure to be somewhat lacking in desirability.

In spite of this, *it must be recognized that there is justification for an attempt at application of wage incentives to production processes which are not simple and straightforward.* If variations in labor requirements, machine capacities, etc., preclude the possibility of developing one constant performance standard, an involved system might be indicated. In such a situation, a Type V structure could

be justified and certainly might prove workable and beneficial.

In the more "typical" situation involving standardized methods, the involved procedure of a Type V structure cannot logically be justified in view of the much less involved Type III methodology. It must be concluded that the basic procedure of the Type III methodology provides the most satisfactory of the approaches here considered for provision of monetary incentive for restricted operations irrespective of the degree of idleness involved.

Limitations Inherent to Evaluation

Any conclusions must take cognizance of the fact that this analysis, on which they are based, has concerned only *written standard operating procedure* of various industrial systems using the various structures indicated. It is apparent that use of "non-standard" procedures to cope with many facets of the subject problem is not uncommon in fact, probably the rule rather than the exception. Development of "fudge-factors" through deliberate misapplication of allowance factors and through intentionally "loose" time values can be used to provide an incentive level of earnings not inherent to the basic system used. Consideration of such "unofficial" individualized development has not been attempted since concern here is with development of satisfactory formal methodology as a solution to the subject problem.

It should also be pointed out that conclusions reached here have not considered the possibility that increased idleness in a work cycle will automatically make possible higher levels of performance during unrestricted portions. It is felt that source material supporting this contention does not provide evidence conclusive enough to justify inclusion in these considerations.

In final conclusion, it must be emphasized that final success or failure of a wage incentive program is not dependent alone on objective merits of the system used. Exceptional administration might very well result in a satisfactory program in spite of defective methodology. It is certainly true that *the existence of a perfect mechanism does not guarantee a satisfactory program, except as it is satisfactorily administered.* With proper consideration of non-mechanical factors, however, it would appear that the standard-hour system (or its equivalent), modified to provide incentive for all manual work and to provide compensation at a lesser level for enforced idleness, can serve as the vehicle for provision of certain desirable motivations with respect to performance of restricted industrial operations.

REFERENCES

Belcher, David W., *Wage and Salary Administration*, New York, Prentice Hall, Inc., 1955.

Emerson, James F., "Multiple Factor Incentives for Process Industries," *The Journal of Industrial Engineering*, Vol. VII, No. 4, July-Aug., 1956.

Llewellyn, R. W., "An Investigation of the Effects of Machine Time on Operator Pace," *M.S. Thesis*, Purdue University, 1948.

Michael, L. B., *Wage and Salary Fundamentals and Procedures*, New York: McGraw-Hill Book Company, 1950.

Mundel, Marvin E., *Motion and Time Study*, revised edition, New York: Prentice Hall, Inc., 1955.

Riegel, John W., "Essentials in Incentive Compensation," *AMA Personnel Series No. 77*, 1944.

Scheib, J. C., "An Analysis of Provisions for Compensation for Restricted Time in the Development of Time Standards for Wage Incentives," *Ph.D. Thesis*, University of Minnesota, 1956.

Whyte, William, *Money and Motivation*, New York: Harper and Brothers, 1955.

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Mathematical Man-Machine Analysis

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The man-machine relationship is an old problem in industrial engineering circles. As an old problem, it has a traditional approach—the man-machine chart. This pictorial device teamed with mathematics, however, renders our analysis of man-machine relationships far more effective and greatly improves our decision-making information.

To get a notion of mathematics' role, let's consider the three basic man-machine relationships.

1. *Completely Systematic.* The machine in this case has a known time interval between requests for attention and there is a known and highly constant operator time when attending. Such a systematic arrangement can be portrayed algebraically with simple linear functions as will be demonstrated later in the discussion.

2. *Completely Random.* In this case, it is not known exactly when a machine will request service nor is it known how long the serviceman, in a specific situation, will take. Averages are known, however, and with these averages, probability mathematics can be employed effectively, as well as servo-mechanism mathematics. This is a queueing or waiting line problem about which much has been written. (1)

3. *Systematic-Random Mixture.* Between the two above extremes are all shades of mixtures. Moving from the completely random towards the systematic, probability can work for part of the distance. For instance, random machine breakdown with regular service time—an average time with low variation—is treated by probability. Even regular but highly varying machine requirements coupled with regular service is successfully characterized by probability. As the machine battery gets small, however, and a systematic servicing predominates, any widely spaced but random interruption to that system appears to require a mixed approach—algebra and probability combined.

This discussion proposes to display a case study of such a combined approach to a man-machine relationship that is partially systematic and partially probabilistic. The role of simple algebra in the systematic phase will first be emphasized, then the overlay of probability on the algebraic model. Man-machine charting had been done in this problem for a long time both in development work and in the work measurement activity. It was costly, however, requiring 4000 to 5000 engineering hours a year just to maintain incentive standards. Moreover, the engineering answers both on standards and in development work were not completely satisfactory. Accordingly, a comprehensive mathematical model was sought in order to simplify standards maintenance and give broader scope to development work.

FIG. 1. Kodacolor Printer Work Center. Operator is making prints on two of three available printing beams. Note: The printer gate on beam three is shown as normally positioned for print exposure.

This case study concerns the Kodacolor printer. This printer makes the exposure from a Kodacolor negative on Kodacolor paper which is subsequently developed photographically into a Kodacolor print. The Kodacolor printer (See Figure 1) consists of three photographically independent projection systems (beams) which permits the operator to handle three customer orders simultaneously. The operator loads a negative to the printing gate of one beam and depresses a classification button which starts the machine on its automatic cycle. When the printing cycle is complete, the negative is automatically disposed to a negative tray. The operator loads negatives across the three beams whose gates are located beside each other on an inclined panel facing the operator. When three exposures have been made, the paper advances to accept the next three exposures. This procedure is also performed over just two beams when the paper supplied to the printer is of such a width as to accept only two exposures. So, the Kodacolor printer is a semi-automatic electronic complex with two or three semi-independent functions each with a series of sequential elements and associated operator attention elements.

This description might mean more if a sketch of a specific situation were made. In the overly simplified example below (Figure 2) these conditions prevail:

There are 2 beams.
Operator loading element = d = .03 minutes
Print exposure time = a = .05 minutes
Paper advance time = x = .01 minutes
Operator idle time = i
Machine idle time = m

Note that Beam No. 1 will not recommence element (a) until the paper advance (x) has taken place simultaneously on all beams. Also note that operator element (d) cannot coincide with machine element (a) in that beam, but *can* coincide with machine element (x). This latter fact causes the pattern to go two cycles before repeating, where a cycle is defined as the elapsed time between the start of two successive paper advances. That is, cycles 1, 3, and 5 = .08 while cycles 2, 4, and 6 = .09.

Now, the calculation of the time to make a print under these conditions is perfectly straightforward:

Average cycle time = .085 minutes
2 prints per cycle
$\therefore$ .085/2 = .0425 = minutes per print

(Start up time, in an extended run, is negligible). This is the conventional approach to a simple systematic man-machine relationship—a man-machine chart followed by arithmetic calculations. For different conditions—changes in the number of beams, d, a, or x—a new chart would be drawn and calculations made. To examine many conditions would involve considerable sketching even in this basic example. Man-machine charting, as any industrial engineer who has worked with it will testify, is a laborious procedure for any sort of comprehensive analysis.

Turning to mathematics, it's possible to build a simple mathematical model of this system that permits direct calculation of productivity, machine idleness, and operator idleness for any set of conditions.

Let us reconstruct a portion of the above operator machine chart:

These observations are readily made:

1. The elapsed time per cycle (y) is the sum of *operator busy* elements (d) and *operator idle* elements ▯ (blocked area)

$$y = \text{operator busy} + \text{operator idle}$$

2. The operation consists of repeating systematic arrangements over two cycles as noted before (four prints made).
3. The systematic arrangement can be expressed algebraically as follows *over two cycles*:

$$\text{operator busy} = 4(d)$$

$$\text{operator idle} = (a + x - d) \text{ for 1st cycle}$$

$$= a - d \quad \text{for 2nd cycle}$$

or

$$(a + x - d) + (a - d) = (2a + x - 2d)$$

The total elapsed time per cycle (y) becomes

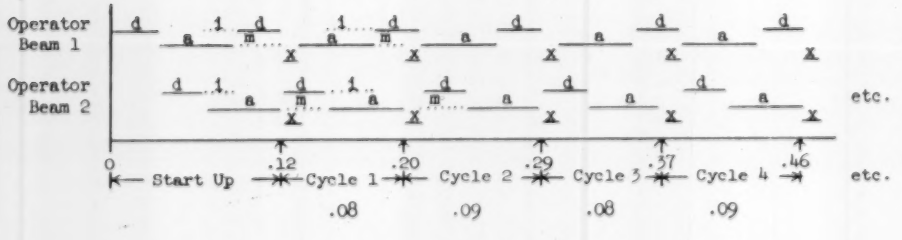

Fig. 2

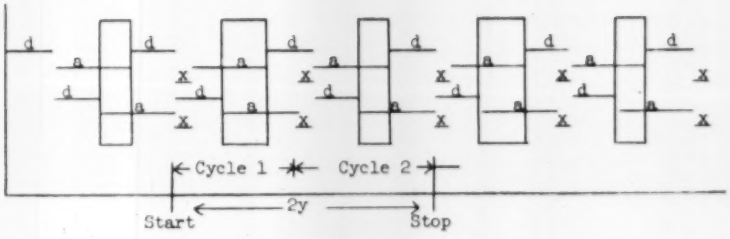

FIG. 3

$$y = 2d + \frac{(2a + x - 2d)}{2}$$

And considering that the number of beams is 2, the average time per print (t) becomes:

$$t = \frac{y}{2} = \frac{2d + \frac{(2a + x - 2d)}{2}}{2} = d + \frac{2a + x - 2d}{4}$$

For our example: $d = .03$, $a = .05$, $x = .01$, $n = 2$

$$t = (.03) + \frac{(2)(.05) + .01 - (2)(.03)}{4}$$

$= .0425$ minutes per print.

I = operator idleness per print

$= 2a + x - 2d = .0425$ min.

M = machine idleness per print

= total time − machine time

$= t - \frac{(a + X)}{2}$

$= .0425 - .03 = .0125$ min.

All this is rather elementary, but it does show how simple algebraic generalization can eliminate the elaborate reproduction of man-machine charts for every new situation in a systematic problem. With the above model, any two beam situation quickly can be analyzed for any combination of d, a, and x. Charting, admittedly, was initially important in understanding the system—mathematics captures that understanding for perpetual use. Extending this to three beams, for instance, requires some charting of the three beam situation. From such a chart, a simple generalization involving d, a, x, and now n (n = number of beams) evolves. We will not discuss this, however, for there is another direction of complexity that is more important.

The printer, as described up to date, has shown only systematic behavior. But note that the roots of both random and systematic behavior exist. The three beams operate with mechanical *independence* up to the point of the simultaneous paper advance. If it were not for the tie-in associated with paper advance, the three beams could be considered as three separate machines attended by one operator. This partially independent feature is the basis for random behavior; it is only systematic when one variable—the *number of prints made for each negative*[1]—is constant. This variable controls the frequency of occurrence of the negative handling element (d). Up to now in our description, prints per negative has been equal to one for every negative considered; i.e., each print made had a negative handling element. This is not unrealistic since it matches the actual experience of handling "process and print" orders—those orders wherein a customer sends in an undeveloped roll of Kodacolor Film requesting development of the negative and one print each.

There is another type of work, however, defined as "print only" work. A customer sends in separate negatives already developed (from previous "process and print" work) and requests one or *more* prints (say 2, 3, sometimes 20 or 50) from such negatives. In this kind of work, the partially random behavior exhibits itself. The number of prints made from each negative is not necessarily the same; the negatives to be printed occur in a completely random manner—that is, knowing what *this* negative requires in the way of prints is not necessarily an indication of what the *next* one or the one on the other beam will require. So, in any given cycle, the printer can be working, on one beam, on a single print negative, and on the other beam, on the third print of a five print negative. Or maybe the combination is six of six on the first beam and one of two on the second, and so forth. Now, if that paper advance linkage connecting the beam action did *not* exist, these beams could be considered as two or three *separate* machines (as noted earlier) attended by one operator and *subject to the conventional multiple machine probability analysis*. The constant re-alignment of these partially independent functions, however, gives the printer this mixed-up behavior—partially systematic, partially random.

[1] There is another variable also—the number of negatives per order involving operator order handling time. An order is the customer package. For simplicity in explanation, this order handling element will not be considered. Its treatment parallels that of prints per negative.

Before examining the approach to this combined problem in detail, let's summarize briefly. The Kodacolor printer can be considered as having these basic variables:

n = The number of beams in operation simultaneously, usually two or three

d = Negative loading time. The operator loads the negative in the gate and depresses the classification button. This is a measured time value dependent on the negative size and type of order handled.

a = Print exposure time. This may be values from 2.5 to 5.5 seconds for current machine designs. However the value is a constant for a given machine for a given period.

x = Paper advance time which is fixed for all printers. This is the time the machine takes to index the paper for the next series of exposures.

R = The average number of prints-per-negative for that order type. This may be any value ≥ 1.0.

These variables are the minimum required to retain the character of the problem. The actual operation consists of other equally important elements that will be left out now for ease of explanation.

The problem is to determine the expected production from a Kodacolor printer for any set of given values for the variables shown above.

As before, here is a specific example:

$n = 2$ (number of beams)

$d = .03$ (operator time to load a negative)

$a = .05$ (printer time for one exposure)

$x = .01$ (printer time for paper advance)

These orders are a random selection of "print only" work to be printed on two beams:

	Beam #1			Beam #2		
	No. of Negs.	No. of Prints	Prints /Neg.	No. of Negs.	No. of Prints	Prints /Neg.
Order	4	4	1	2	6	3
Supply	2	6	3	2	4	2
	1	3	3	8	8	1
	3	3	1	4	4	1
	3	6	2			
Total	13	22		16	22	

No. Negatives to be handled = 29.

No. Prints to be made = 44.

Average prints/negative = $R = \frac{44}{29} = 1.5$

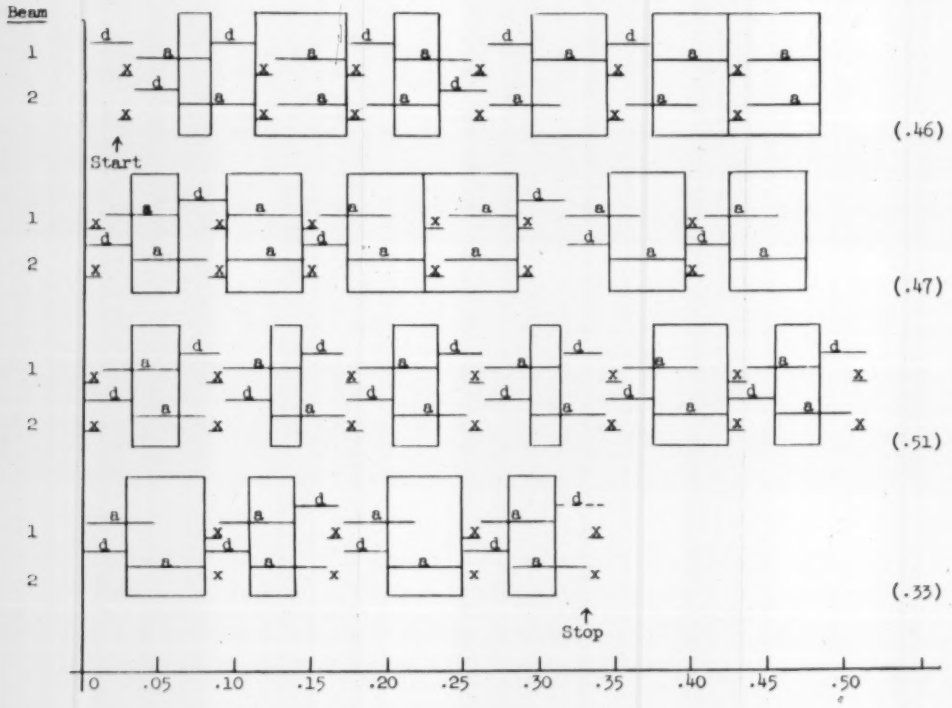

FIG. 4

As shown earlier, a solution to the problem can be attained by the construction of an operator-machine chart as shown in Figure 4.

Total time (Y) = 1.77 minutes
Operator busy = .87 minutes

for 22 cycles: $\frac{.87}{22}$ = .0395 min/cycle

Operator idle = .90 minutes

for 22 cycles: $\frac{.90}{22}$ = .0410 min/cycle

.0805 min/cycle

Time per print (t) = $\frac{.0805}{2}$ = .0403 min/cycle

From this chart, as before, print productivity can be calculated (disregarding, for the moment, the blocked in operator idle times):

Total time = 1.77 minutes (minus start up)
Total cycles = 22
Average Cycle Time = 1.77/22 = .0805 min.
and Average Time per print = $\frac{.0805}{2}$ = .0403 min.

This chart value, however, would not be acceptable as a final one since this collection of work is only a partial one, albeit random. The chart is just a fleeting 1.77 minutes of activity perhaps never to recur in exactly the same way. More charting would be required for *this* set of conditions to say nothing of other values for a, d, x and R. Charting alone to crack this problem is now an immense chaotic job even for this simplified version of the operator-printer relationship. Using both algebra and probability, however, it is possible to build a mathematical model that describes the system once and for all.

We can use the chart of this specific example to get some idea of how the system as a whole operates. As noted before:

$$\text{Time per Cycle} = y = \text{operator busy} + \text{operator idle}$$

$$\frac{\text{Operator Busy}}{\text{Per Cycle}} = \frac{\text{Sum of the } (d) \text{ values}}{\text{No. of Cycles}}$$

$$\frac{(.03)(29)}{22} = \frac{.87}{22} \cong .04 \text{ (in figure 4)}$$

This operator busy time can be developed into a more convenient form as follows:

$$= \frac{(d)\ (\text{no. of negatives})}{\text{No. of Cycles}}$$

$$= \frac{(d)\ (\text{no. of negatives})}{\text{No. of Prints}/2}$$

$$= 2d \div \text{No. Prints per Negative}$$

$$= \frac{2d}{R} = \frac{(2)(.03)}{1.5} = .04 \text{ minutes}$$

The idleness elements—shown as blocks in Figure 4—now need to be described to complete the mathematization.

Examining Figure 4 closely, we can see that the amount of the idleness element depends more or less on whether or not there is a negative handling element in that cycle. If there is no negative handling it means the printer is working in other than the first print of a multiple print negative. The printer does this automatically acting on operator instructions registered by a pushed button when the negative was originally loaded.

We can redefine the system, in Figure 4, therefore, in terms of whether a cycle has or doesn't have a negative handling element. Below, "d" in Figure 4 indicates that a negative is handled to make a print in a cycle and "0" indicates that no negative handling occurs in the cycle.

Beam #1 $d\ d\ d\ d\ d\ d\ 0\ 0\ d\ 0\ 0\ d\ 0\ 0\ d\ d\ d\ d\ 0\ d\ 0\ d\ 0$
Beam #2 $d\ 0\ 0\ d\ 0\ 0\ d\ 0\ d\ 0\ d\ d\ d\ d\ d\ d\ d\ d\ d\ d\ d$

Here are all possible combinations:

$$\text{Beam \#1} \begin{vmatrix} 0 \\ \text{Beam \#2} \end{vmatrix} \begin{vmatrix} 0 \\ 0 \end{vmatrix} \text{ or } \begin{vmatrix} d \\ 0 \end{vmatrix} \text{ or } \begin{vmatrix} 0 \\ d \end{vmatrix} \text{ or } \begin{vmatrix} d \\ d \end{vmatrix}$$

We can improve this knowledge by seeking a statement of *how frequently* each combination occurs or what the probability is of the combination occurring.

With these definitions:

$\begin{vmatrix} 0 \\ 0 \end{vmatrix}$ = P_0 = Probability of getting no negative in a cycle

$\begin{vmatrix} d \\ 0 \end{vmatrix}$ or $\begin{vmatrix} 0 \\ d \end{vmatrix}$ = P_1 = Probability of getting one negative in a cycle.

$\begin{vmatrix} d \\ d \end{vmatrix}$ = P_2 = Probability of getting two negatives in a cycle.

We can consider the occurrence of "d" and "0" as random[2] and use these probability statements.

$$P_0 = \frac{(R-1)^2}{R^2}$$

$$P_1 = \frac{2(R-1)}{R^2}$$

$$P_2 = \frac{(R-1)^2}{R^2}$$

For Example: Solution for P_1, where $R = 1/3$:
Probability that a negative is handled for a print to be made the occurrence of $(d) = 1/R$ or $1/3$.
Probability that no negative is handled for a print to be made the occurrence of $(0) = \left[1 - \frac{1}{R}\right] = \frac{(R-1)}{R} = \frac{2}{3}$

[2] In any one beam, "d" and "0" are not independent since the number of prints per negative in any one order is likely to be similar. There is, then, a "bunching" effect within a beam. The work in one beam, however, is independent of work in another beam and the aggregate effect at any cross-section (cycle) approaches complete randomness as more beams are included. Within beam dependency is really quite slight so that the 2 beam effect exhibits this randomness for all practical purposes as the 3 beam effect also does.

$$P_1 = \begin{vmatrix} d & \\ 0 & \end{vmatrix} \text{ or } \begin{vmatrix} 0 & \\ d & \end{vmatrix} = \frac{1}{R} \times \frac{(R-1)}{R} + \frac{(R-1)}{R} \times \frac{1}{R}$$

$$= 2\,\frac{(R-1)^1}{R^2} = \frac{2 \cdot 2}{9} = \frac{4}{9}$$

Note that this could have been expressed as

$$\begin{bmatrix} n! \\ 1!(n-1)! \end{bmatrix} \frac{(R-1)^{n-1}}{R^n}$$

Where n = number of beams

These probability statements are for individual cycles. Idleness, however, has a two cycle pattern as the first systematic example showed (see Figure 2 and the comments). Any expression that would yield a value for idleness must relate to combinations over *adjacent* cycles — not individual cycles. Accordingly, we can expand our list of possible combinations and note opposite a new definition using the previous definitions as a basis:

	Combination	Defined as
a.	$\begin{vmatrix} 0 & 0 \\ 0 & 0 \end{vmatrix}$	P_0P_0
b.	$\begin{vmatrix} 0 & 0 \\ 0 & d \end{vmatrix}$ or $\begin{vmatrix} 0 & d \\ 0 & 0 \end{vmatrix}$	$P_0P_1 = P_1P_0$
c.	$\begin{vmatrix} 0 & d \\ 0 & d \end{vmatrix}$	$P_1P_2 = P_2P_1$
d.	$\begin{vmatrix} 0 & d \\ d & 0 \end{vmatrix}$ or $\begin{vmatrix} 0 & 0 \\ d & d \end{vmatrix}$ or $\begin{vmatrix} d & 0 \\ 0 & d \end{vmatrix}$ or $\begin{vmatrix} d & d \\ 0 & 0 \end{vmatrix}$	P_1P_1
e.	$\begin{vmatrix} d & d \\ 0 & d \end{vmatrix}$ or $\begin{vmatrix} 0 & d \\ d & d \end{vmatrix}$	$P_1P_2 = P_2P_1$
f.	$\begin{vmatrix} d & d \\ d & d \end{vmatrix}$	P_2P_2

Charting these possible adjacent cycle combinations (or observing in Figure 4 when they do occur) permits the development of idleness expressions in terms of a, x, and d for certain groups of these combinations. These are shown below:

	For These Conditions	These Idleness Expressions Prevail Average Idleness cycle
1.	P_0P_0	1. $a + x$
2.	$\begin{bmatrix} P_0P_1 \text{ or } P_1P_0 \\ \text{or} \quad \text{or} \\ P_0P_2 \quad P_2P_0 \end{bmatrix}$	2. $\dfrac{(2a + x)}{2}$
3.	$\begin{bmatrix} P_1P_1 \\ \text{or} \\ P_1P_2 \text{ or } P_2P_1 \end{bmatrix}$	3. $\dfrac{(2a + x - d)}{2}$
4.	P_2P_2	4. $\dfrac{(2a + x - 2d)}{d}$ (See figure 2)

The above four idleness expressions are the *only* expressions that exist for all the possible adjacent cycles combinations. These expressions tell *how much* idleness occurs; the associated probability statements can tell *how frequently*; combining both will give a *total idleness* picture. Determining the probability of getting each of the idleness expressions is done by following the basic probability rules;

"and" means multiply the probability expressions

"or" means add the probability expressions

Consider the "P_0P_0" combination:

P_0 to occur *and* P_0 to follow:

$$P_0 \times P_0 = P_0^2$$

Consider the "P_0P_1 or P_1P_0" combination:

P_0 to occur *and* P_1 to follow *or* P_1 to occur *and* P_0 to follow:

$$(P_0P_1 + P_1P_0) = 2\,(P_0P_1)$$

Thus, all the probability statements can be developed and combining them with the idleness expressions results in a final mathematical model for the system that is represented by the example in Figure 4:

y = operator busy: $\dfrac{2d}{R}$ (as shown before)

+

operator idle: $P_0^2(a + x)$

$$+ 2P_0(P_1 + P_2)\frac{(2a + x)}{2}$$

$$+ P_1(P_1 + 2P_2)\frac{(2a + x - d)}{2}$$

$$+ P_2^2\frac{(2a + x - 2d)}{2}$$

The calculation using the model for the example:

$$P_0 = \frac{(R-1)^2}{R^2} = \frac{(1.5-1)^2}{(1.5)^2} = \frac{.25}{2.25} = .110$$

$$P_1 = 2\,\frac{(R-1)^1}{R^2} = 2\,\frac{(1.5-1)^1}{(1.5)^2} = \frac{1.0}{2.25} = .445$$

$$P_2 = \frac{(R-1)^0}{R^2} = \frac{(1.5-1)^0}{(1.5)^2} = \frac{1.0}{2.25} = .445$$

	Total	1.000
P_0^2	= .01	R = 1.5
$2\,(P_0)(P_1 + P_2)$	= .20	d = .03
$P_1\,(P_1 + 2P_2)$	= .60	a = .05
P_2^2	= .19	x = .01
Total	1.000	

Model:

$$y = \frac{2d}{R} + P_0^2(a + x) + 2P_0(P_1 + P_2)\frac{(2a + x)}{2}$$

$$+ P_1(P_1 + 2P_2)\frac{(2a + x - d)}{2} + P_2^2\frac{(2a + x - 2d)}{2}$$

$$= \frac{(2)(.03)}{1.5} + (.01)(.06) + (.20)\frac{(.11)}{2} + (.60)(.04) + (.19)\frac{(.05)}{2}$$

$$= .04 + .0006 + .0111 + .0240 + .0047$$

$$= .0804 \text{ min. cycle}$$

$$t = .0804 \div 2 = .0402 \text{ min. per print}$$

This compares very favorably with the actual value from the Figure 4 chart of .0403 minutes per print. It gives a good idea of the adequacy of the model. This close correspondence is not always realized in such a short run, of course; the model portrays the average long run productivity and short run differences between actual and predicted are to be expected within statistical limits.

It should also be noted that the actual system may not repeat itself on every other cycle as it did in the purely systematic case (Figure 2). Using the adjacent cycle notion as a base again reflects an average condition. The cycles repeat in a random fashion, actually, reflecting the probability overlay on the systematic relationship.

This mathematical model for a systematic—probabilistic man-machine relationship has one main feature: it describes and quantifies a finite reasonable (say <15) number of situations and attaches a probability to each situation. These quantities for each situation multiplied by their probabilities and summed give a weighted total picture. In a more generalized form:

t = time per print

$t = b + i$ $\quad b$ = operator busy time

$= f(d, R, n)$ $n = 2$ in this discussion

$\quad i$ = operator idleness

$= \sum_j P_j i_j$

P_j = probability of the jth condition arising

$= g(R, n)$

i_j = idleness associated with jth condition

$= h(a, x, d)$

j = the number of the possible condition

$= 1, 2, 3, \cdots k$ $\quad$ where k is finite and reasonably small (<15)

This last restriction is opinion—it would seem that the complete probability approach (as described in the conventional queueing theory literature of reference 1) is suggested if the possible number of conditions gets too high. In the complete Kodacolor Printer Model, for instance, $k = 8$.

There have been some extremely beneficial results from this specific mathematical model. It has been programmed on the Card Programmed Calculator[4] (recall that there are several more variables and complexities in the complete model) which has permitted a new dimension in development work. Where five or, at most, a dozen combinations of possible new conditions was the limit in man-machine charting—at that, incomplete—the upwards of 200 or so were recently examined and completely so on the calculator. Moreover, 3000 industrial engineering hours have been released in work measurement areas as a result of this model. Work Measurement posed a continuing problem of changing standards on a dozen or so varieties of printers to keep pace with the constant improvements being made by electronic engineers. And, finally, no adequate assessment can be made of the secure knowledge that the answer is "right" and not just the end point of an incomplete engineering analysis.

One question that arises on such models is the treatment of input data as though it were rigidly fixed. Operators certainly differ and any one operator varies in successive element times. These facts raise no problem, however, operators have a productivity directly proportional to their individual average time on the operator-paced portion of work. Within operator variation "averages out"—the realignment of the system every cycle eliminates the usual waiting line problem of service time being irrevocably lost if servicing idleness occurs. So, generally speaking, the Central Limit Theorem protects against variation all the way through and average (or, if you wish, "standard") times are usable.

Whenever analytical methods seem complex it suggests the use of Monte Carlo or simulation techniques. Of course, man-machine charting is a "poor-man's" Monte Carlo—a *very* poor man, we might add—and it points up some of the difficulties. This simulation would be heavily loaded with alternatives as each new item of data is added. Selecting alternatives with numerous rules to follow is not easy on conventional punched card equipment and is not cheap on the more elaborate electronic data processing machines. In this problem the latter was not available; it is honestly hard to say at what point analytical complexity will tip the scales toward Monte Carlo. Analytical methods, such as this mathematical model, do give the engineer a certain grasp of the problem—a conceptual control—that is very advantageous in intelligent handling of it. But man-machine charting, in the vastly more competent guise of electronic simulation, may eventually prove the winner.

That is not immediate, however, and man-machine analysis as currently done by charting *can* be improved by mathematics. This discussion has shown simple algebra in action on a purely systematic relationship and has dwelt at some length on handling a mixed situation—partly systematic, partly random. Basic probability and

[4] This was handled by Mr. Bart Allen and Mr. Robert H. Morris, Department Head, Scientific Computing Department, Eastman Kodak Company.

simple algebra can be used in the latter case—both within the easy grasp of practicing industrial engineer. These two approaches to these two aspects of the man-machine problem join with the third approach—probability or servomathematics, to the third aspect—the largely random behavior. And the industrial engineer has a highly effective attack on man-machine productivity problems—a mathematical attack that makes an immeasurable improvement over the traditional man-machine charting.

REFERENCES

(1) Came, G. D., "Bounding the Solutions of Practical Queueing Problems by Analytical Methods", *Operations Research for Management* Vol. II, edited by J. F. McCloskey and J. M. Coppinger, the Johns Hopkins Press, Baltimore, Md. 1956

(2) Feller, W., *Probability Theory and Its Applications*, John Wiley and Sons, New York, 1950

(3) Fetter, R. N., "The Assignment of Operators to Service Automatic Machines" *Journal of Industrial Engineering*, Sept. Oct. 1955

(4) Jones, W. Dale, "Simplified Incentives for Multiple Production", *Advanced Management*, June, 1950

(5) *MIT Summer Course in Operations Research*, Technology Press, Massachusetts Institute of Technology, Cambridge, Mass., 1953

(6) Sandberg, K. O. W., "A Research Report on Interference Delays in Multiple Machine Assignments", *Transactions of the SAM Time Study and Methods Conference*, New York, April 1953

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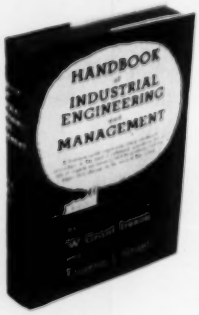

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A Graphic Method for Finding Required Number of Time Study Readings

By B. L. Hansen*

Ordnance Management Engineering Training Program

One of the questions a time study engineer frequently finds himself confronted with is "How many readings of an element should I take to get accuracy?" It is insufficient to say "accuracy" alone since he must be concerned with "how much" accuracy is desired; so it is conventional in practice to place these accuracy limits at ± some percentage of the average.

Currently, there are popular systems in use which give an estimate of the number of readings required based upon a single range between the highest and lowest readings in a series of readings of an element. While these systems no doubt are adequate in many situations, it is a well established fact that a single range by itself is a notoriously poor statistic for estimating dispersion especially so in large samples. The proposed system is no more difficult than those presently in use and is much more accurate, especially when erratic readings occur.

The system proposed below makes use of the average range of small subgroups of a sample in the construction of a graph for finding the additional number of time study readings required after taking the initial study. Let us say we have taken a dozen readings. The sequential procedure is as follows:

1. Take an initial sample of 12 readings of element time.
2. Sum the readings. (Σ = symbol for the summing operation)
3. Divide the readings into four subgroups of 3 each in the order taken.
4. Compute the range of each subgroup. (High minus low)
5. Sum the four ranges.
6. Compute the quotient of the ratio sum of readings to the sum of ranges. ($\Sigma X / \Sigma R$)
7. Locate the computed ratio on the horizontal scale of Figure 1 and read N' off the curve which contains the desired accuracy. The obtained value of N' is the total number of time study readings required to assure the accuracy desired. Note: There are curves for accuracy of ±5% and ±10% of the average. These curves give 95% assurance that the true time study average will be within these ± accuracy limits. The rationale for their development is contained in Addendum 1.

The specific advantages of this system are:

1. An extreme reading is given less weight, therefore, the system is more accurate than the single range system.
2. Required computations are simple and may be performed quickly on the spot.
3. The system is simple, graphic, and eye appealing.
4. The chart could be reduced in size and superimposed on a portion of the time study rating form. If this were done, the constant presence of this system would do much to insure that the time study man would take the required number of readings.

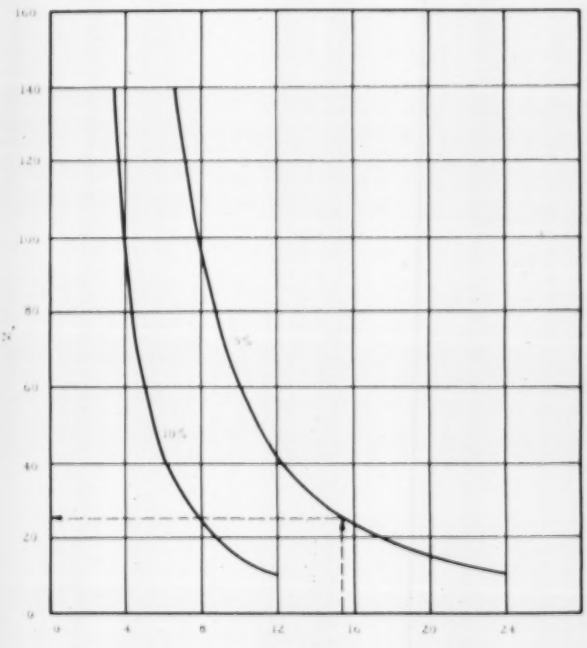

FIG. 1

An example of the required computations and use of the curves follows:

Let us suppose that the following listed time study readings of an element have been made. The required computations of ΣX and ΣR are performed as shown:

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	Readings	Ranges
X_1	08	
X_2	09	
X_3	08	01
X_4	08	
X_5	06	
X_6	07	02
X_7	07	
X_8	08	
X_9	09	02
X_{10}	07	
X_{11}	08	
X_{12}	08	01
	$\Sigma X = .93$	$\Sigma R = .05$
	$\Sigma X/\Sigma R = .93/.06 = 15.5$	$\bar{X} = .93/12 = .079$

Consulting Figure 1 for accuracy of ±5%, 25 readings are required. This means that 13 additional readings are required. These must be taken immediately since this system assumes a homogeneous sample. If accuracy of ±10% is satisfactory, enough time study readings have been taken and it may be assumed that at least 95% of the time the true average time of this element would be between ±10% of the sample average. For this example, 10% of the average confidence limits would be placed at .079 ± .10 (.079) or at .087 and .071. It must be remembered that use of Figure 1 requires that a dozen readings be taken and that these dozen readings be broken into subgroups of 3 each. Use of any other sample and subgroup sizes than these would require the building of other specific curves.

Should such be desired, substitution of the proper constants in the rationale on Addendum 1 would enable their construction. Since, in many plants, it is common practice to take an initial study of 10 readings, a reasonable approximation of the required number of readings may be obtained by splitting the 10 readings into 5 subgroups of 2 each, performing the required computations and reading N' off the curve containing the desired accuracy.

For illustration, using the first 10 readings of our example, the sum of the first 10 readings = 78 and the sum of the 5 ranges = 5 $\Sigma X/\Sigma R = 78/5 = 15.6$. A $\Sigma X/\Sigma R$ value of 15.6 gives a corresponding N' of 25.

It will be noted that the curves terminate at an N' of 140. The choice of a termination point was arbitrary in the sense that out of an infinite number of termination points, 140 was chosen. Nonetheless, a termination point had to be selected, and in practice, it is likely that the savings in accuracy obtained by taking an N' of, say 200, would offset by the cost of taking the readings.

Addendum 1

Problem: To find number of time study readings which will give 95% confidence that true mean of the time study is within $\pm k\bar{X}$.

1. From problem set $.05\bar{X} = \dfrac{t\sigma'}{\sqrt{n'}}$, where
   $k = .05$
   t = constant at $n - 1$ degrees of freedom and k level of significance

   but $\bar{X} = \dfrac{\Sigma X}{n}$ and $\sigma' = \dfrac{\bar{R}}{d_2}$ where
   $\bar{R}$ = average range
   d_2 = mean relative range

2. $\dfrac{\Sigma X}{20_n} = \dfrac{t\bar{R}}{d_2\sqrt{n'}}$ but $\bar{R} = \dfrac{\Sigma R}{m}$ where
   m = number of subgroups

3. For subgroup sample size of 3, $m = 1/3n$, and $d_2 = 1.693$

$$\therefore \frac{\Sigma X}{20n\ \frac{1}{3}n(1.693)\sqrt{n'}} \text{ and } \Sigma X = \frac{20n\ t\Sigma R}{\frac{1}{3}n(1.693)\sqrt{n'}}$$

$$= \frac{60\ t\Sigma R}{1.693\sqrt{n'}} = \frac{35.4\ t\Sigma R}{\sqrt{n}}$$

4. $\dfrac{\Sigma X}{\Sigma R} = \dfrac{35.4t}{\sqrt{n'}}$ and $n' = \left(\dfrac{35.4t}{\Sigma X/\Sigma R}\right)^2$

5. t for .05 level of significance, four subgroups of three each and $n - 1$ degrees of freedom = 2.201, hence $35.4t = 78$.

6. Hypothesizing various values of $\Sigma X/\Sigma R$ enables a curve of coordinates of N' and $\Sigma X/\Sigma R$ to be built for four subgroupsof three readings each.

   NOTE: The combination of four subgroups of three each was chosen as a good representative combination after many other combinations of n items and m subgroups had been examined.

$\Sigma X/\Sigma R$	N'
6	169
8	95
10	61
12	42.2
14	31
16	23.7
18	18.8
20	15.2
22	12.5
24	10.5

7. The same rationale may be used for building a curve for k of .10

Setting $.10\bar{X} = \dfrac{t\sigma'}{\sqrt{n'}}$

$$\frac{\Sigma X}{10n} = \frac{t\bar{R}}{d2\sqrt{n}} = \frac{t\Sigma R}{\frac{1}{3}n(1.693)\sqrt{n'}}$$

$$\text{and } \Sigma X = \frac{30\ t\Sigma R}{1.693\sqrt{n'}} = \frac{17.7\ t\Sigma R}{\sqrt{n'}}$$

$$\text{and } \frac{\Sigma X}{\Sigma R} = \frac{17.7\ t}{\sqrt{n'}} \qquad t \text{ for } n - 1 \text{ degrees of freedom} = 2.201$$

$$\text{and } n' = \left(\frac{39}{\Sigma X/\Sigma R}\right)^2$$

A curve for k of .10 and for 4 subgroups of 3 each may be built from the following coordinates:

$\Sigma X/\Sigma R$	N'
3.5	124
4	95
5	60.7
6	42.2
7	31
8	23.7
9	18.8
10	15.2
11	12.5
12	10.5

The Assignment Problem—A Special Case of Linear Programming[1]

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The simplex and distribution (transportation) methods of linear programming (1) are being increasingly used for solving problems in industry. There are, however, some special problems of the linear programming type which also have many industrial applications and which are important in their own right. One such problem is the assignment problem. In this paper we shall indicate the usefulness and application of a technique, developed by Flood, for solving the assignment problem (2, 3).

Introduction

As an illustration of a situation where the assignment technique is applicable, consider the following simplified example:

The highway maintenance department of a township has n ($n \geq 3$) road repair crews which it wishes to assign to n different repair jobs. There is a different but known cost associated with the assignment of each crew to each job. The problem is to assign one crew to each separate job in such a way that all crews are assigned and the total cost of the assignment is minimized.

This type of problem can be translated to many other industrial applications. For example, it might be required to assign n pieces of material handling equipment (each suited in a different way to perform different jobs) to n jobs so as to minimize the total cost or time or distance traveled.

Assignment problems could also involve the maximization of a criterion. Thus, it might be required to assign n available persons to perform n jobs in such a way that each person is assigned to one, and only one, job and the total production (using an appropriate criterion such as standard man-hours) is maximized. Here the assumption is that the effectiveness of each available person for each job is known.

A case involving n facilities and n jobs has $n!$ possible arrangements for making the complete assignment. Thus for $n = 3$, and denoting

$$x_{ij} = \begin{cases} 1, \text{ if facility } i \text{ is assigned to job } j \\ 0, \text{ otherwise} \end{cases}$$

tables 1(a) through 1(f) indicate the six possible assignments (solutions). These tables are called *permutation matrices*.[2]

Permutation Matrices

All Possible Solutions For $n = 3$

Table 1 (a)

Facility	Job 1	Job 2	Job 3
1	1		
2		1	
3			1

Table 1 (b)

Facility	Job 1	Job 2	Job 3
1	1		
2			1
3		1	

Table 1 (c)

Facility	Job 1	Job 2	Job 3
1		1	
2	1		
3			1

Table 1 (d)

Facility	Job 1	Job 2	Job 3
1		1	
2			1
3	1		

Table 1 (e)

Facility	Job 1	Job 2	Job 3
1			1
2		1	
3	1		

Table 1 (f)

Facility	Job 1	Job 2	Job 3
1			1
2	1		
3		1	

[1] For a more detailed discussion, see Vaswani, R., "The Assignment Problem" in *Introduction to Operations Research*, C. W. Churchman, R. L. Ackoff, and E. L. Arnoff (eds.), John Wiley & Sons, Inc., New York, 1957.

[2] As is customary, zeros have been omitted from these permutation matrices.

Certain characteristics of these permutation matrices might be noted. In each matrix only one element in a row is unity and all other elements are zeros. Similar remarks apply to elements in columns. This is so because the condition of our problem stipulates that each facility should be assigned to one, and only one, job and each job should be performed by one, and only one, facility.

If we have a *cost matrix* which gives the cost associated with assigning facility i to job j, we could "cost" each of these six solutions and choose the minimum-cost solution. However, for even moderate values of n this way of solving the problem, by enumerating all possible solutions, becomes impractical. For instance, for $n = 20$, the total number of permutation matrices is

$$20! = 2{,}432{,}902{,}008{,}176{,}640{,}000.$$

No modern electronic computer would be able to solve this optimal assignment problem by the simple enumeration method within reasonable time.

Mathematical Model

We shall now develop a mathematical model for the assignment problem using the following notation:

i = index of Facility ($i = 1, 2, \cdots, n, n \geq 3$)

j = index of Job ($j = 1, 2, \cdots, n, n \geq 3$)

a_{ij} = Cost associated with assigning facility i to job j, with the a_{ij} real numbers, not necessarily bounded

$A = \| a_{ij} \|$ = Cost matrix

$$x_{ij} = \begin{cases} 1, & \text{if facility } i \text{ is assigned to job } j \\ 0, & \text{otherwise} \end{cases} \qquad (1)$$

$X = \| x_{ij} \|$ = Permutation matrix

T = Total cost of complete assignment

The assignment problem requires finding values of the x_{ij}'s subject to condition 1 such that

$$\sum_{i=1}^{n} x_{ij} = \sum_{j=1}^{n} x_{ij} = 1, \qquad (2)$$

Which minimizes

$$T = \sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij} x_{ij}. \qquad (3)$$

Flood has shown that this assignment problem is a special case of the distribution problem of linear programming (2). Hence it could be solved by using algorithms which are appropriate for solving the distribution problem. However, special and efficient techniques, called the Hungarian Techniques, for solving the assignment problem have been developed. These techniques are based on the following two theorems:

Theorem I:[1] If the elements of a matrix consist of zeros and non zeros, then the minimum number of lines that contain all of the zero elements is equal to the maximum number of zero elements no two of which lie on the same line. (In this theorem, a line means a row or a column.)

Theorem II: If from a matrix $A = \| a_{ij} \|$, we obtain another matrix D by means of the transformation

$$d_{ij} = a_{ij} - u_i - v_j,$$

with u_i and v_j arbitary constants, the optimization problem in A represented by conditions 1, 2, and 3 is identical with that in D.

Flood's Technique

Kuhn was the first person to use these two theorems for developing a technique for solving the assignment problem (6). Flood's technique is also based on these two theorems and offers the futher advantage that it reduces the cost matrix rapidly and results in a substantial saving in time (3, 4).

An outline of Flood's algorithm is given below:

(i) *Step 1.* Examine the columns of cost matrix A, identifying the smallest element v_j ($= \min_i a_{ij}$) in each. Form a new matrix A_1' by replacing a_{ij} with

$$a_{ij}' = a_{ij} - v_j, \text{ for } i, j = 1, \cdots, n.$$

This new matrix will contain at least one null (zero) element in each column.

(ii) *Step 2.* Find a minimal set of lines, S_1', that includes all null elements of A_1'. Let n_1' be the number of lines in S_1'. If $n_1' = n$, there is in A_1' a set of n null elements, no two of which are in the same line, and the elements of A in these n positions constitute the required solution.

For example, by applying step 1 to matrix A in Table 2, we obtain matrix A' (Table 3). A possible set of lines to include all null elements in A' consists of columns 1, 2, 3, and 4. This set consists of four lines. However, the minimal set of lines, which in this case has but two lines, consists merely of rows 3 and 4. Hence S_1' = {rows 3, 4} and $n_1' = 2$.

It might be noted that in some problems the set S_1' will not be unique.

(iii) *Step 2'.* If $n_1' < n$, examine the rows of A_1', identifying the smallest element u_i ($= \min_j a_{ij}'$) in each. Form a new matrix $A_1 = \| a_{ij}^{(1)} \|$ by means of the transformation

$$a_{ij}^{(1)} = a_{ij}' - u_i.$$

This matrix will contain at least one null element in each row and in each column.

(iv) Now follow step 2 as before. If $n_1 = n$, there is in A_1 a set of n null elements, no two of which are in the same line, and the elements of A in these n positions constitute the required solution. *Cycle (1)*

TABLE 2

Matrix A

Facility	Job 1	2	3	4
1	6	8	7	5
2	4	10	8	6
3	7	5	6	4
4	3	4	10	7
Min, a_{ij}	3	4	6	4

TABLE 3

Matrix A'

Facility	Job 1	2	3	4
1	3	4	1	1
2	1	6	2	2
3	4	1	0	0
4	0	0	4	3

[1] This theorem was proved by the Hungarian mathematician D. Konig in 1916 (see ref. 5). Hence a technique for solving the assignment problem which makes use of this theorem is called "The Hungarian Technique for the Assignment Problem."

(v) *Step 3.* If $n_1 < n$, let h_1 denote the smallest element of A_1 not in any line of S_1. Subtract h_1 from each element of A_1 not in S_1, and add h_1 to each element that lies at an intersection (if any) of lines of S_1; call the resulting matrix A_2.

Check by means of step 2 if $n_2 = n$.

(vi) If not, repeat the cycle until at some cycle k (where $k = 1, 2, \cdots$), $n_{k+1} = n$. Then matrix A_{k+1} will give the optimal solution as in (iv) above.

The accompanying flow diagram (Figure 1) indicates the technique with individual steps.

It might be noted, parenthetically, that steps 1, 2′, and 3 follow directly from theorem II according to which replacement of a_{ij} by d_{ij}, where

$$d_{ij} = a_{ij} - u_i - v_j,$$

with u_i and v_j arbitrary constants, does not change the optimization problem (for a detailed explanation, see ref. 7).

A desirable feature of Flood's algorithm is that it is self-corrective in the sense that if at any stage we make an error in selecting the set S_k, such that n_k is greater than the minimal number of lines required to cover all zeros (but less than n) in matrix A_k, the computations are not thereby invalidated. This type of error will automatically be corrected in subsequent stages.

Illustration

The application of Flood's optimal assignment technique will be illustrated by means of the following example:

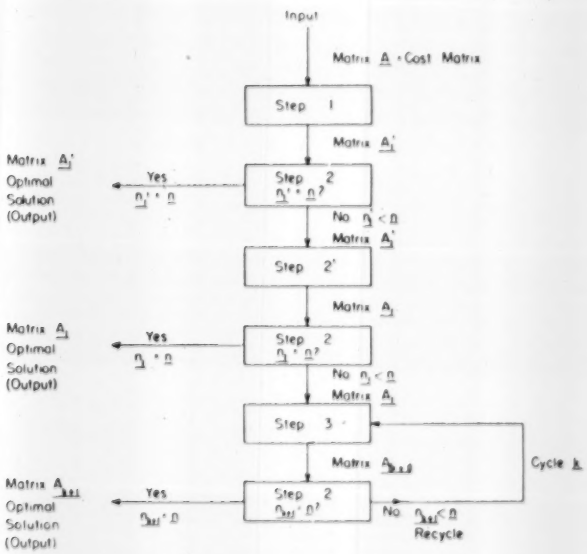

FIG. 1. Flow Diagram Showing Flood's Optimal Assignment Algorithm

Cycle from Step 3 to Step 2 until at the earliest cycle k (where k takes on positive integral values), $n_{k+1} = n$. Then matrix A_{k+1} will give the optimal solution(s).

Note: Input to and output from Step 3 for the k-th cycle are matrices A_k and A_{k+1} respectively.

A paint factory has ten identical manufacturing units (numbered $i = 1, \cdots, 10$) and can therefore process simultaneously ten batches of paint. It has orders for manufacturing ten different paints (numbered $j = 11, \cdots, 20$)[6] and although these ten paints are all similar in the sense that they require the same processing time, they differ with respect to qualities such as color which necessitate that each paint be manufactured by a different unit. The cost of processing any of these paints is the same regardless of the unit on which it is manufactured.

However, before a paint is manufactured on a unit, it is necessary to clean or convert the unit to make it suitable for the particular batch of paint which is to be manufactured. This cost of conversion would include the cost of cleaning the vats and kettles and will depend upon the color and quality of paint that was manufactured on the unit before the conversion and on the paint which is to follow after conversion. If the paint that preceded is exactly the same as that which will follow, the cost of conversion, *variable with the assignment*, will be zero.

We can now construct cost matrix A (Table 4) in which each element a_{ij} represents the cost of conversion if unit i is converted to make it suitable for manufacturing paint j. Thus we see from matrix A that if paint 14 is assigned to unit 3, the conversion cost will be \$139, for example.

TABLE 4

Matrix A

Dollar Cost of Conversion

Unit No.	Paint No.									
	11	12	13	14	15	16	17	18	19	20
1	577	551	996	918	620	699	246	328	761	608
2	716	640	699	706	697	983	557	462	617	423
3	737	205	313	139	706	326	529	283	502	257
4	701	557	270	666	309	129	865	989	899	933
5	533	869	653	992	351	146	564	546	203	634
6	431	313	1033	242	645	768	364	876	1001	820
7	262	930	578	941	680	430	579	449	280	254
8	662	428	882	879	398	491	540	277	540	837
9	354	529	985	753	338	181	237	595	227	585
10	303	946	512	773	805	191	431	799	232	274
v_j = Min. a_{ij}	262	205	270	139	309	129	237	277	203	254

Subtract v_j from each element of column j ($j = 11, \cdots, 20$) to obtain matrix A_1'.

The problem is to assign units to paints in such a way that the sum of manufacturing costs is minimized. Since the processing cost for each paint is assumed to be the same regardless of the unit on which it is manufactured, the problem is really to assign units to paints such that the sum of conversion costs is minimized.

We now proceed to apply Flood's optimal assignment technique.

[6] For convenience, j has been given values 11, $\cdots$ 20 instead of 1, $\cdots$ 10 so that the rows and columns of the matrices can be referred to as lines 1, $\cdots$ 20.

TABLE 5

Reduced Matrix A_1'

	Unit No.	Paint No. 11	12	13	14	15	16	17	18	19	20	$u_i' = \text{Min}_{(j)}$	
	1	315	346	726	779	311	570	9	51	558	354	9	
	2	454	435	429	567	388	854	320	185	414	169	169	
***	3	475	0	43	0	397	197	292	6	389	3	0	***
***	4	439	352	0	527	0	0	628	712	696	679	0	***
***	5	271	664	383	853	42	17	327	269	0	380	0	***
	6	169	108	763	103	336	639	127	599	798	566	103	
***	7	0	725	308	802	371	301	342	172	77	0	0	***
***	8	400	223	612	740	89	362	303	0	337	583	0	***
***	9	92	324	715	614	29	52	0	318	24	331	0	***
	10	41	741	242	634	496	62	194	522	29	20	20	

*** Indicates lines of S_1'.

$S_1' = \{3, 4, 5, 7, 8, 9\}$; $n_1' = 6 (< n)$.

Subtract u_i' from each element of row i ($i = 1, \ldots, 10$) to obtain matrix A_1'.

Step 1. In order to obtain matrix A_1' (Table 5), we find the minimum element v_j in each column of matrix A and write it in the row below matrix A. For instance, $v_{11} = 262$, $v_{12} = 205$, etc. We now subtract 262 from every element in column 11, 205 from every element in column 12, and so on, and obtain matrix A_1' which has at least one null element in every column.

Step 2''. The minimum number of lines which can cover all zeros in matrix A_1' is six. $S_1' = \{$lines 3, 4, 5, 7, 8, and 9$\}$, and $n_1' = 6 < n$. Hence the optimal solution matrix has not been reached.

Step 2'. Since $n_1' < n$, we find the minimum element u_i' in each row of A_1' and write it on the extreme right side of A_1'. Thus $u_1' = 9$, $u_2' = 169$, etc. We now subtract 9 from each element of row 1, 169 from each element of row 2, and so on, and obtain A_1 (Table 6). The resulting matrix will have at least one null element in each line.

Step 2''. The minimum number of lines which can cover all zeros in matrix A_1 is 8. Hence the optimal solution matrix has not been reached and we proceed to step 3.

Step 3. We find h_1, the smallest element of A_1, ignoring all elements covered by lines of S_1. ($h_1 = a_{6,12} = 5$.) We add 5 to each element at the intersection of lines of S_1 and subtract 5 from each element of A_1 not in S_1 to obtain A_2 (Table 7).

TABLE 6

Reduced Matrix A_1

	Unit No.	Paint No. 11	12	13	14	15	16	17	18	19	20	
	1	306	337	717	770	302	561	0	42	549	345	
	2	285	266	260	398	219	685	151	16	245	0	
***	3	475	0	43	0	397	197	292	6	389	3	***
***	4	439	352	0	527	0	0	628	712	696	679	***
***	5	271	664	383	853	42	17	327	269	0	380	***
	6	66	5	660	0	233	536	24	496	695	463	
***	7	0	725	308	802	371	301	342	172	77	0	***
***	8	400	223	612	740	89	362	303	0	337	583	***
	9	92	324	715	614	29	52	0	318	24	331	
	10	21	721	222	614	476	42	474	502	9	0	

*** Indicates lines of S_1.

$S_1 = \{3, 4, 5, 7, 8, 14, 17, 20\}$; $n_1 = 8 (< n)$.

$h_1 = a_{6,12} = 5$.

Add 5 to each element at the intersection of lines of S_1 (elements $a_{3,11}, a_{3,12}, a_{4,11}, \ldots, a_{8,20}$) and subtract 5 from each element that is not in S_1 to obtain A_2.

TABLE 7

Reduced Matrix A_2

	Unit No.	Paint No. 11	12	13	14	15	16	17	18	19	20	
	1	301	332	712	770	297	556	0	37	544	345	
	2	280	261	255	398	214	680	151	11	240	0	
	3	475	0	43	5	397	197	297	6	389	8	
***	4	439	352	0	532	0	0	633	712	696	684	***
	5	271	664	383	858	42	17	332	269	0	385	
	6	61	0	655	0	228	531	24	491	690	463	
	7	0	725	308	807	371	301	347	172	77	5	
	8	400	223	612	745	89	362	308	0	337	588	
	9	87	319	710	614	24	47	0	313	19	331	
	10	16	716	217	614	471	37	174	497	4	0	

*** Indicates lines of S_2.

$S_2 = \{4, 11, 12, 14, 17, 18, 19, 20\}$; $n_2 = 8 (< n)$.

$h_2 = a_{5,16} = 17$.

Add 17 to each element at the intersection of lines of S_2 and subtract 17 from each element that is not in S_2 to obtain A_3.

TABLE 8

Reduced Matrix A_3

	Unit No.	Paint No. 11	12	13	14	15	16	17	18	19	20	
	1	301	332	695	770	280	539	0	37	544	345	
	2	280	261	238	398	197	663	151	11	240	0	
***	3	475	0	26	5	380	180	297	6	389	8	***
***	4	456	369	0	549	0	0	650	729	713	701	***
***	5	271	664	366	858	25	0	332	269	0	385	***
***	6	61	0	638	0	211	514	24	491	690	463	***
***	7	0	725	291	807	354	284	347	172	77	5	***
	8	400	223	595	745	72	345	308	0	337	588	
	9	87	319	693	614	7	30	0	313	19	331	
	10	16	716	200	614	454	20	174	497	4	0	

*** Indicates lines of S_3.

$S_3 = \{3, 4, 5, 6, 7, 17, 18, 20\}$; $n_3 = 8 (< n)$.

$h_3 = a_{10,\ 13} = 4$.

Add 4 to each element at the intersection of lines of S_3 and subtract 4 from each element that is not in S_3 to obtain A_4.

TABLE 9

Reduced Matrix A_1

	Unit No.	Paint No. 11	12	13	14	15	16	17	18	19	20	
	1	297	328	691	766	276	535	0	37	540	345	
	2	276	257	231	391	193	659	151	11	236	0	
***	3	175	0	26	5	380	180	301	10	389	12	***
***	4	456	369	0	549	0	0	654	733	713	705	***
***	5	271	664	366	858	25	0	336	273	0	389	***
***	6	61	0	638	0	211	514	28	195	690	467	***
***	7	0	725	291	807	354	284	351	176	77	9	***
	8	396	219	591	741	68	341	308	0	333	588	
	9	83	315	689	610	3	26	0	313	15	331	
	10	12	712	196	610	150	16	174	197	0	0	

*** Indicates lines of S_1.

$S_1 = [3, 4, 5, 6, 7, 17, 18, 19, 20]$; $n_1 = 9 (< n)$.

$k_1 = a_{7,17} = 3$.

Add 3 to each element at the intersection of lines of S_1 and subtract 3 from each element that is not in S_1 to obtain A_2.

We repeat steps 2 and 3, starting with matrix A_2, until we reach matrix A_5 (Table 10), wherein $n_5 = 10 = n$. The optimal solution matrix has now been reached. This optimal assignment is indicated by the symbols [0] (to be read as *independent zeros*) in matrix A_5. This assignment is also indicated in Table 11.

Notice that since our assignment in Table 10 has been selected from zero elements, no other assignment can be cheaper than the one selected. Also, according to theorem II, the minimization problem represented in Table 10 is identical with that in Table 4, the minimum-cost solution in Table 10 is also the minimum-cost solution with respect to Table 4.

It is worth noting that for this example there are

$$10! = 3{,}628{,}800$$

possible arrangements of assigning ten units to ten batches of paint. The conversion cost of each of these possible arrangements will be between the minimum cost of $2641 and the maximum cost of $8771, with only one assignment at each extreme, because both the minimum-cost and the maximum-cost assignments are unique. (This can be seen, for the former case, from Table 10, in which there is but one set of independent zeros.) The maximum-cost figure of $8771 is obtained from a problem related to that which has been exhibited and corresponds to the worst possible assignment. Computationally, the finding of the maximum cost consists of nothing more than finding the minimum "cost" assignment when the matrix of conversion costs, $A = |a_{ij}|$, is replaced by the new matrix $B = -A = |-a_{ij}|$. (To make the elements of B into non-negative numbers, it then suffices to add the constant 1033 (the largest element in the matrix A) to each. (This procedure is clarified below.) The assignment resulting in maximum cost is given in Table 12. From the foregoing discussion it

TABLE 10

Reduced Matrix A_5

Final Matrix

	Unit No.	Paint No. 11	12	13	14	15	16	17	18	19	20
	1	294	325	688	763	273	532	[0]	37	540	345
	2	273	254	231	391	190	656	151	11	236	[0]
	3	175	[0]	26	5	380	180	304	13	392	15
	4	456	369	[0]	549	0	0	657	736	716	708
	5	271	664	366	858	25	[0]	339	276	3	392
	6	61	0	638	[0]	211	514	31	198	693	470
	7	[0]	725	291	807	354	284	354	179	80	12
	8	393	216	588	738	65	338	308	[0]	333	588
	9	80	312	686	607	[0]	23	0	313	15	331
	10	9	709	193	607	147	13	174	197	[0]	0

*** Indicates lines of S_5.

$S_5 = [11, 12, 13, 14, 15, 16, 17, 18, 19, 20]$; $n_5 = 10 (= n)$.

Hence the optimal solution may be obtained from the set of null elements in A_5. The optimal assignment has been indicated by [0].

TABLE 11

Minimum Cost Assignment

Unit No.	Paint No.	Cost of Conversion ($)
1	17	246
2	20	123
3	12	205
4	13	270
5	16	146
6	14	242
7	11	262
8	18	277
9	15	338
10	19	232
Total cost = T		2641

TABLE 12

Maximum Cost Assignment

Unit No.	Paint No.	Cost of Conversion ($)
1	19	761
2	16	983
3	11	737
4	17	865
5	14	992
6	18	876
7	12	930
8	20	837
9	13	985
10	15	805
Total cost		8771

can be seen that any method or procedure that does not guarantee the selection of an optimal solution will result in a total cost somewhere between the above two figures.

Special Applications

There are many special cases of the assignment problem three of which are briefly mentioned below. The reader is referred to Vaswani (7) for a more detailed discussion of this topic.

1. The problem of assignment might involve a maximization criterion. For the sake of concreteness, we shall consider a case of profit maximization. Here, we start out with a profit matrix C each element c_{ij} of which represents the profit to be earned by assigning facility i to job j. Next, we convert matrix C into matrix $B = \|b_{ij}\|$ by means of the following transformation:

$$b_{ij} = \operatorname{Max}_{ij}(c_{ij}) - c_{ij}, \quad \text{for all } i, j, \quad (4)$$

where,

$\operatorname{Max}_{ij}(c_{ij})$ = The maximum element in matrix C.

Using matrix B as our initial matrix (like the one referred to as the cost matrix A in this paper), we can apply Flood's optimal assignment technique and proceed exactly as in the minimization problem.

2. Technological, legal, or other restrictions might prohibit the assignment of a facility to some specific job. Such a restriction can be taken care of by setting the pertinent element, say the (i, j) one,

$$a_{ij} = M, \quad (5)$$

where M is an arbitrarily large positive number. Computationally, the addition to, or subtraction from M of any finite number results (effectively) in M.

3. The number of available facilities n might exceed the number of jobs m to be performed ($m < n$). In such a case, the cost matrix can be made square by introducing $n - m$ columns for dummy jobs and by associating zero cost with the assignment of each facility to each dummy job. The technique for solving this case is the same as that discussed above with the exception that step 2′ will be eliminated.

Concluding Remarks

Many analytic techniques exist for solving the optimal assignment problem. One such technique developed by Flood (which belongs to the class of techniques commonly known as the Hungarian Method) considerably reduces the computational work, with respect to more general techniques.

The usefulness of the optimal assignment technique arises in many situations such as the setting up of assembly lines in mass production, making schedules for machines (especially those requiring large setup times) in job shops, assigning personnel to jobs, and setting up sound stages for shooting sets in film studios.

REFERENCES

(1) *Activity Analysis of Production and Allocation*, T. C. Koopmans (ed.), John Wiley & Sons, Inc., New York, 1951.

(2) Flood, M. M., "On the Hitchcock Distribution Problem," *Pac. J. Math.*, *3*, 2, June 1953, pp. 369-386.

(3) ———, "The Traveling Salesman Problem," *Operations Research*, *4*, 1, Feb. 1956, pp. 61-75.

(4) ———, "The Traveling Salesman Problem," in *Operations Research for Management*, II, J. F. McCloskey and J. M. Coppinger (eds.), The Johns Hopkins Press, Baltimore, Maryland, 1956, pp. 340-357.

(5) Konig, D., *Theorie der Endlichen und Unendlichen Graphen*, Chelsea Publishing Co., New York, 1950.

(6) Kuhn, H. W., "The Hungarian Method for the Assignment Problem," *Nav. Res. Log. Q.*, *2*, 1 and 2, Mar.-June 1955, pp. 83-98.

(7) Vaswani, R., "The Assignment Problem," in *Introduction to Operations Research*, C. W. Churchman, R. L. Ackoff, and E. L. Arnoff (eds.), John Wiley & Sons, Inc., New York, 1957.

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A Manager Appraises Operations Research*

By R. A. Norman

Manager Marketing, Cathode Ray Tube Department, General Electric Company

Although this paper is entitled "A Manager Appraises Operations Research" it is more accurately an appraisal of Operations Synthesis. It briefly recounts the conceptual background to a study conducted in conjunction with Professor Andrew Schultz, Jr. and his staff at Cornell University, the purpose of which was to construct a model of a business and to explore some applications of the model. As such, it can only be considered a first step, but a very necessary step, toward Operations Research.

The Term "Operations Synthesis"

Operations Synthesis may be considered as the application of the systems concept to a business. By dictionary definition, "synthesis" is "the putting together of parts or elements so as to form a whole" or "a whole made up of parts or elements put together." To "synthesize" is "to bring together into a whole by synthesis" or "to form by bringing together separate parts." As applied to an operation or a business, synthesis is an attempt to create an analogy of the total business or system in terms of the individual elements or functions which go to make up the total system.

A business may be considered as a complex system for getting certain work done. In most cases, it may be considered as a continuous process, operating in a closed loop. To take a simple example, in a manufacturing business, raw materials are purchased, transported to a factory, processed into a finished product, moved through distribution channels and sold to a customer, whose money is used to start the whole cycle over again, or more properly, sustain the entire cycle, with the fond hope, of course, that there is some money left over for the owners. The entire system is made up of a number of functions: not only the physical flow and processing of the material, but also the acquisition, delivery and storage of the raw material, the creation of a desire to buy on the part of the consumer, the distribution of the finished stock, and all of the other work that makes up a business. All of these efforts are combined to finally deliver the product to the point of use, realize a value for the work performed, and regenerate the cycle.

Operations synthesis is directed at determining what the various functions of the system are, how they contribute to the total, how they are interrelated and interact. More than that, it is directed at defining the individual elements precisely—preferably mathematically—in terms of the total system, so that they may be evaluated and understood, and so that the probable effect of a change of the individual elements on other elements and on the total system may be gauged. In essence, it is an attempt to understand the basic nature of a business system; with such an understanding it is then possible to bring into play the techniques of research to indicate better ways to accomplish the end purpose of the system.

Scope of the Paper

The following is a discussion of an effort that was directed toward analyzing and synthesizing a business system as an entity. The study is discussed along the following lines:

1. The nature of the problem.
2. The initial difficulties encountered in attempting to solve the problem.
3. The development of new concepts for approaching the solution of the problem.
4. The final development of a model of the business.
5. The conclusions drawn from the model.
6. Some conclusions as to the general application of the concept developed in the study.

The Nature of the Problem

The Business Studied

The particular business under consideration is the cathode ray tube business; that is, the design, production, and marketing of television picture tubes. The principal raw material is the glass envelope. In addition, a number of metal parts are purchased and assembled to form the electron gun. Tubes are produced by depositing a phosphor screen on the surface of the bulb, vaporizing an aluminum backing on the screen, applying inside paint, baking the bulb, sealing in the gun, evacuating the entire assembly, and finally, finishing the tube with a base and outside paint.

There are two primary markets for television picture tubes. The sale of tubes for use in original equipment is characterized by high volumes of a relatively small number of different types, delivered to relatively few locations on

*Prepared for the Industrial Engineering Seminars at Cornell University, June, 1956.

a highly seasonal basis. The sale of tubes for replacement use is characterized by a large variety of types, sold through distributors and service dealers all over the nation, again on a highly seasonal pattern. In recent years, the use of "trade-in" bulbs, that is, the glass envelope from a worn-out tube, has become a significant factor in the replacement market.

The Problem

The decision to restudy this business in itself assumed that the system could be restructured to perform the total function more efficiently. The initial question was "How can the same net service be performed with less work? How can the product be delivered to the customer for less cost?"

The obvious first point of attack would be to assume that one or more of the individual functions is being performed inefficiently. This approach assumes first that the management of the function is less than effective and second, that the group performing the study is capable of better understanding of the function than those directly responsible. Although either or both of those assumptions are not untenable, for purposes of the study it was assumed that specific functions were performed effectively within the frame of reference in which they were operating. In other words, the relative efficiency of the individual functions was accepted as given; the study addressed itself to the structure of the organization and the relationship between functions.

What to Change?

Even under this assumption, it became evident first that the possible areas for change were altogether too numerous for "trial and error" handling, and secondly, that no specific change could be evaluated independently of the rest of the system.

An illustration will serve to point up the problem: The case of inventory policy. In the first place it is necessary to determine whether inventory control is or is not an important part of the total function of the business. In a supermarket, inventory control may be an extremely important function. Such a business is primarily concerned with having the right goods available in the right place at the right time; inventory is a primary function. Management effort must be directed toward controlling this function. On the other hand, in the turbine business, where products are manufactured to specific order, finished stock inventory is a problem of a different order. Management effort is directed toward design and production efficiency. The function of the business, the service performed, is basically different. Hence the first question may well be, what are the important functions of the business? How important *is* inventory control? Where does it fit in the general scheme of things? Should considerable effort be spent on it, or should it be relegated to a secondary position?

Assuming that inventory control is an important function of the business, it then becomes necessary to determine the extent to which other elements of the business can be sacrificed to achieve a satisfactory inventory policy.

Here we are faced with a whole series of factors. From the marketing standpoint, the ability to serve customers must be preserved, but at the same time, the cost of warehousing must be gauged. From the manufacturing standpoint, short-runs, set-up time, the variety of products in the shop at one time must be minimized. From the employee relations standpoint, lay-offs and training time must be minimized. Engineering wants to preserve the ability to refine developments and bring out new products without risking the obsolescence of finished goods in stock. Finance is concerned with capital tie-up, as well as other carrying costs.

One normal approach to this problem is to develop an inventory policy based on experience and, sometimes, on the relative immediate domination of manufacturing or marketing problems in the organization. Then an estimate or a budget is constructed dealing in this policy along with a number of similar policies to finally create a total representation of the business. If the net result is unsatisfactory, it is adjusted until a more satisfactory result is developed. Occasionally, two or three complete budgets may be constructed, each based on different policies, in an attempt to determine the most productive direction, but normally, this is a monumental task. Ideally, it would be desirable to construct twenty or thirty or more budgets, each reflecting a different course of action or combination of courses of action. From these, we could begin to develop a feel for some of the possibilities open to us, a feel for the relative balance between elements of our business, and establish plans and policies on a more logical and rational basis.

When the problem of studying our total business was examined, we were faced with exactly the sort of problem discussed above, except that it was not restricted to inventory control; it involved essentially all possible courses of action. We were convinced there was a better way to operate the business; that the same total function could be performed for less cost. There were a number of possible avenues of approach, possible combinations of manufacturing and distribution policies, which offered a chance to improve the efficiency of operation. The number of such possibilities, however, was almost unlimited. Hence, the traditional approach of constructing total budgets of the entire business for a number of choices and combination of choices was completely impractical.

How to Approach

It became necessary to develop some sort of technique that would permit us to determine:

1. Where changes in the system might be possible, practicable, and productive.
2. How much change could be expected in a given area.
3. What counter-effects such changes might have.

If such information could be developed, the number of possible points of attack could be narrowed down and effort concentrated on the areas which could be expected to be most productive. Thus, with some indication of the interactions involved we could intelligently set about the task of balancing and optimizing changes for the maximum impact on the results of the total system.

The Initial Investigation Work

If space permitted, it would be interesting to review in detail the initial work that was done on the project. For fully six weeks, a wide variety of blind alleys was explored, all of which produced precisely nothing as far as specific answers were concerned. The experience was very valuable because out of it the concepts were developed which led to, first, being able to state the problem, and second, a means of adequately describing the business in terms of function. A brief review may be helpful in fully understanding the final results.

Problems of Relationship

Early in the study, it became evident that existing accounting records were inadequate for the purposes of this work, and perhaps it would be worthwhile to discuss some of the reasons why traditional accounting is inadequate. To begin with, the Electro Motive Force that keeps the whole system going is profits, and these are usually expressed in dollars. This has led to the use of dollars as a medium of expression to describe the functions of a business system. Obviously, there can be no basic quarrel with this, provided it is remembered that dollar cost figures are *symbols* for functions and not the actual function or work effort itself. Accounting is concerned with *accumulating* these symbols and combining them to represent the net effect of a series of functions. This study was concerned with isolating and differentiating between functions.

This was precisely the sort of difficulty that developed in our initial attempts to attack our problem. When we attempted to evaluate the cost of serving different markets, we found our results confused by differences in plant operations. When we attempted to compare different plant operations, we found our results confused by product or market differences.

For example, two tubes of the same type, sitting in a warehouse, represent for all practical purposes, identical items. Their source of manufacture, the difference in the distance they traveled to get to the warehouse and all of the other factors that preceded their arrival at the specific point at the particular time (assuming no quality differences) does not create any differential in value at that point. Accumulative cost systems may state two entirely different values, but for practical purposes, no differentiation exists. Similarly, their ultimate destination has no effect on what they are at that point. One may go to a replacement user, at a higher selling price and with higher selling and distribution costs. The other may go to an equipment manufacturer for installation in a set. At the point when the tubes are sitting side by side in the warehouse, this makes no difference in their value or their identification.

If we were faced with but a single or a few such "cross-over" points, our problem would not be so difficult, but in practice such cross-over points occur repeatedly throughout the entire system. For example, glass breakage in our plants is an ever present problem. Again assuming no quality differences, glass breakage as a function is independent of the price of the bulbs or the way in which it was transported to the plant and must be treated separately. From the accounting standpoint, and for that matter, from any other standpoint, it is important to know that ten dollars is invested in a glass envelope when it is broken. On the other hand, if that ten dollars includes an extra two dollars that could have been avoided by better transportation methods, this has no relationship to bulb losses. As a practical matter, the extra two dollars would make a reduction in bulb losses appear even more attractive than it would normally be. A bulb loss is a fact by itself, and the transportation cost of a bulb is a fact by itself. The two are interrelated, but they are separate functions. Confusing the two leads to a variety of false conclusions when we attempt to analyze functions.

Accountants, however, are concerned with building costs to an end point and in order for them to do this, they must consider the total loss at the point where the breakage occurred. Their position is, of course, valid, in that when the bulb was broken, everything that had been spent on it to that point was lost, regardless of whether the costs up to that point represented an efficient expenditure or not. This approach does not tell us, however, whether efforts should be concentrated on improving transportation costs, bulb costs, or bulb losses. It is conceivable that in order to get lower bulb costs, we might want to take a little more breakage, but this then gets into efficiency of manufacturing equipment utilization and a number of other problems.

These illustrations should serve to show the kinds of difficulties we came into as we worked with our normal accounting records. It was almost impossible to separate the individual functions of our business, and to express them independently. We kept working closer and closer to the central idea: the business is a system of work functions, a mechanism for doing certain work. It can be analyzed in terms of how well it performs that work. With a full understanding of the functions to be performed, the relative contribution of individual functions, their interrelationships, we have the opportunity to re-design the

system to operate with greater efficiency. Costs are a valuable means of describing work functions, but they must be recognized as symbolic representations of work, and not realities in themselves. This is particularly important when we begin to add costs together and combine descriptions of different work functions.

The Development of a New Approach

A Schematic of the Business

As these thoughts began to crystallize, and as we began to realize that the records at hand would not produce the required results at least in their existing form we decided to approach the problem in a new way. Our first step was to lay out the functions of our business in the form of a flow chart in which we attempted to describe in broad terms what actually goes on in our business. We started out with various material elements that we purchase. The next step was the movement of those materials from the original source of manufacture to our plants. At the plant, the materials are unloaded, inspected, stocked, and started on the manufacturing line. We continued this sort of analysis through processing, finished stock, etc., until the goods were finally delivered to a customer and our money came back to us. Obviously, a chart of this kind can be carried out in greater or lesser detail as the need warrants. In our case, because of the time limitations, we laid it out in a rather simple form, but in sufficient detail to cover all the major functions of the business, all product lines, and all customer classes. Basically, it was a schematic diagram of the entire business.

From this chart we were able to split out, with a fair degree of clarity, the separate functions of the business. We developed a list of some fifty different elements, each with a potential further breakdown by market or customer class and by the eighty odd types we produce. Our criteria for the separation of elements was primarily based on how they were caused or created, and controlled.

Statement of Functions

We then went through the list and attempted to define and describe each one in terms of how it could be measured. For example, starting with our raw materials, we took bulb costs. As I mentioned before, this is an important element in our total costs. Bulbs are bought on an established price basis, with prices varying by size and shape. Our total bulb cost for a period would be a function of the total quantity of each type to be produced times the price for the bulb for that type times a constant to cover bulb losses in processing. The next element might be the transportation costs involved in moving the bulb from the vendor's plant to our plant. This would be a function of the quantity of bulbs by size times the weight for each size times the freight rate between the two points. (This is, of course, a simplified definition of this element, but we need not concern ourselves with the other variables at this point.) The next element might be receiving, inspecting and stocking the bulbs at the factory. This is a different sort of element. Actually it is not directly related to the quantity of bulbs shipped in at all. A receiving and inspection station is set up to handle some sort of a peak load condition and the costs of maintaining that station carry on over a period of time regardless of whether the bulbs come in or not. Hence, these costs are a function of time rather than quantity. When management makes the decision to provide the ability to handle a certain peak load condition for a period, the costs are established and continue until management decides to change that capacity. At the same time, although there is no lower limit, there is an upper limit to what the station can handle; hence, it is important to know what that upper limit is and, if we are to measure the efficiency of the system, the degree to which the capacity is actually used.

In the same fashion, we proceeded through the entire operation. We took each element and attempted to define and describe it; how it was created and how it could be changed. Obviously, this led us into considerable refinement of our original flow chart and segregation of elements. It is important to note that as I have described them so far, these elements have certain definite characteristics For example, they are both independent, and at the same time interdependent. The cost of bulbs and the transportation charges on bulbs have no direct relationship. At the same time, both functions are influenced by the quantity of product flowing. The functions of receiving, inspecting, and stocking of bulbs are again independent of the price of bulbs or the cost of moving bulbs in. If we have two plants located at different distances from our source of supply, the accounting cost of bulbs received at each plant may be considered to be different because of transportation differences. The functions of receiving, inspecting, and stocking, however, are independent of this difference and should be roughly equivalent (or of equivalent value to the end product) at both plants.

The Development of the Model

As we completed our definition of elements, significant patterns and forms began to emerge. First, it became evident that we were dealing with three general types of elements, secondly, we were running into a considerable repetition of data between elements, particularly with respect to common or at least interdependent multipliers, and thirdly, we discovered a significant amount of data which could be stated with fair precision.

Classification of Functions

Considering the three general types of elements, we found a number which we defined as quantity or volume multiplied by a certain cost. Other elements we defined in terms of time; that is, a continuing cost over a certain period of time. Still a third group required a definition in terms of both quantity and time and, in some instances, distance of movement. Hence, we broke our elements down into three major categories, as follows:

1. *Product.* We considered product as the elements which flow through the system. They are the elements which the system works on and which are, in one form or another, ultimately delivered to the consumer. In total, they are a function of volume. For purposes of definition, we treat them in terms of a unit. An example of a product element in our business would be the glass bulb. For every tube we deliver to a customer, at some point of time, we must have acquired a bulb. In one way of looking at it, product may be considered to be a function of design.
2. *Facility.* We considered facility as the system itself, the organization, the manufacturing equipment and all the other elements that go to make up the business. Facilities are, by definition, a function of time; they remain constant over a period of time, regardless of the volume of product flowing through them. It is not enough, however, to define facilities simply in terms of time. They are a function of management decision. Management decides to set up a facility to do a specific job or to have a certain capacity. Once the facility is set up, it continues for a period of time until management decides to change it. It is important to know what the limitations on changes are. In the case of a major facility—a manufacturing plant, for example—the time interval may be quite long, usually a matter of years. In the case of a specific production schedule, the direct and indirect labor manning that is so established may be subject to change in a relatively short period, a matter of weeks. It is only in knowing these limitations that we can determine how much latitude for change we have, and what we can do to meet changing situations. The second important requirement in the description of facilities is the capacity of each element. As mentioned before, a facility is set up to do a certain job; by definition, it continues in existence over some period of time regardless of whether it is actually used or not. If we are to achieve actual maximum efficiency, the facility should be used continuously at capacity throughout the period. This, of course, is rarely possible. If we are to determine the over-all efficiency of the system, however, it is necessary to know the capacity of each element of facility and the extent to which that capacity is used, or conversely, the degree to which that capacity is wasted.
3. *Flow.* This was considered as the element of movement of product through facilities. It involves the idea of the rate of movement, the distance of movement, the number of starts and stops, the duration of interruptions of movement as, for example, in inventory requirements. It includes, of course, the important concept of demand, that is, the actual quantity requirements at the output end of the system which, in many respects, determines the requirements throughout the system.

Repetition of Terms

This last category was, of course, that which led us to a recognition of the repetition throughout the system. We found, as we worked through our flow chart, that we were continually working with quantity factors which, while not identical and subject to a variety of breakdown, were nevertheless all interdependent and interrelated. Actually, they were all derivatives of our output figures. By developing the proper coefficients and coupling them to certain flow characteristics, we could automatically develop the entire flow pattern for the entire system for any given output over a specific period of time.

Predictability of Functions

As we began to develop this general pattern, we came into the third important area: a vast amount of the data required to describe our business system had practically no information content at all. For example, once we listed our selling prices for each type in each market, we could forget about them. We were no longer concerned about them; we were concerned only with the multiplier, the volume figure, which is, of course, the real variable. This is not to say that we could not or would not consider the impact of a change in selling price, but such a change is a single class of data and need not concern the rest of the system. Similarly, once we had listed the purchase price of the glass envelopes for each type (and note that end markets have no effect on this) we could forget them. Again we were concerned about the multiplier—the volume requirements, which, of course, was dependent on the output figure.

The Model

At this point, we were ready to put the entire picture together in the form of an algebraic model. I do not think it is necessary to go into a detailed discussion of the expression of this model or the way it was programmed for the computer. Essentially, this process, while important, is the "crank-turning" step, and is secondary to the conceptional step.

Suffice it to say that a model of the business was produced, programmed for a punched card computer. This model expressed each element of the business individually in its own terms and in terms of its relationship to the entire system. It provided for carrying volume requirements, facilities elements, and product factors as independent statements in such a way that variations in any one or any combination could be introduced as required.

The Conclusions Drawn from the Model

Basically, the model accomplished the following: 1 it permitted us to analyze the functions of our business in terms of relative importance and sensitivity to change, and 2 it gave us a working tool to experiment with possible changes and to measure the impact of such change.

Differences Between Businesses

Let us look first to the analysis of the functions that make up our business. We found first, that in terms of function, we were considering two separate businesses: (1) the replacement business, and (2) the equipment business. In the replacement business, we were serving a market that stretches across the entire country, wherever television sets are in use. Our market is created when a television set breaks down; particularly when the picture tube fails. The owner calls in a repairman who finds the cause of the difficulty. He is not simply a retailer of replacement tubes; he is a service technician, whose job is to find out what the difficulty is and to fix it. The set-owner must rely on him, and thus, this service dealer is our real customer for tubes. In order to adequately serve his customer, he must be able to get the particular type of tube that is required for that set; he must get it quickly and get it installed in the set, so the owner can have his set back in operation. Our job, working through our distributors, is to have that particular type of tube available when he wants it. In addition, when it is considered that the worn-out tube is traded in on the replacement tube and as such, is an important source of raw material, it is fairly evident that the whole logistics problem—the business of transporting tubes from the factory to the point of use, of maintaining adequate but not excessive stocks of all types of tubes, of moving dud bulbs back to the point of use—is an important part of the function performed in the replacement market.

Contrasting the equipment market with the replacement market, we find a quite different situation. Instead of a large variety of types, we find but a few types in style at any one time. Customers are few and centrally located. Orders are for thousands of tubes of a given type, rather than a few tubes of a variety of types. Shipments are scheduled out in carload lots, pallet packed, rather than L. T. L. single packed.

Functions of Each Business

With the help of our model, we were able to break down the individual functions for each market with some, of course, that were unallocable to either and which had to be carried by the total business. It was then possible to look at each one in terms of susceptibility to change, and, more importantly, in terms of its relative importance as a part of the total function performed in serving each market. For example, even though we assume that the labor cost of processing a tube for the replacement market and the equipment market is exactly the same, as a per cent of the total function, it may vary quite significantly. For example (and these figures are purely hypothetical), labor as a part of total in the replacement market may amount to 10%, but in the equipment market, it may amount to 15% or more. This, in itself, is not without significance. If, however, we begin to eliminate some of the elements which cannot be changed, this difference may be extremely significant. For example, in our business, worrying about basic material costs (excluding material losses) is largely a waste of time. As I mentioned before, pricewise it is a standard item, competitively priced in the open market. It is, and must be, a standard design item. For every tube sold, we must buy at least one bulb, just like our competition. Short of going in the glass business, there is little we can do except collect the money from our customers and give it to the glass supplier. As such, basic material costs are a constant. It is just a substance that happens to flow through our system and offers little opportunity directly to us, as tube makers, for change. (Admittedly, I have oversimplified this problem somewhat, but for our purposes of the moment, the general thought will suffice).

Avenues of Change

Taken in this light, the relative importance of labor, *as a possible avenue of change*, takes on a totally different light. On that basis, perhaps in the replacement market, it may become 20% of total, but in the equipment market may go to 40% of the total susceptible to change. In that light, we can begin to throw the two systems into their proper perspective.

In actually piecing our business together, we found that the primary areas for improving the system for the replacement business were in distribution. The elements of transportation, warehousing, handling, and inventory control were primary targets. We found it was necessary to recognize the basic requirement for extreme flexibility in manufacture and special handling of dud glass, to the extent that certain sacrifices in manufacture were involved; in other words, we might tolerate higher manufacturing costs in order to get better distribution costs.

In the equipment market, the problem was quite different. The total area susceptible to change was less, accentuating the importance of each individual element. In examining this problem, we found that here our greatest contribution was in manufacturing and this was chiefly in the work that our facility performed. Basically, we have a big equipment installation; the efficiency of our total system was largely dependent on the efficiency with which we used this essentially fixed facility. Our problem here was largely one of good loading, long runs, limited variety, and peak operating efficiency; factors which were, to an extent, opposite to those operating in the replacement market.

A "Dream" Statement

Obviously, there were many other elements in both markets that required attention and study. We were able, however, to get some insight into the relative importance of each of them, the possibility of change, and where they fit in the over-all picture. Then, through the use of the model, we were able to test them individually and in combination. Finally we attempted to construct a complete new model of the business, using the same terms as we had used in our description of the existing business, but tailoring the structure so as to best suit the specific require-

ments of our markets. Essentially this was a "dream" set-up. It reflected how the business could be set up to meet the existing situation and was not limited by considerations of the structure as we now know it. A detailed comparison of this with our present business not only gave us a measure of the potential of the business, but also pointed out the specific areas of weakness in our present structure.

Variables

As I mentioned earlier, up to this point we worked within specific volume requirements and under present market conditions. The next step, then, was to begin to vary those requirements and to introduce future possibilities. At this point, we introduce extremely important unknowns. Obviously a device of this kind is not going to predict the future, nor is it going to make management decisions. It does, however, lend itself to providing information as to what might happen under a variety of future circumstances or management decisions. For example, the elements that will be affected by a change in volume had been isolated. Hence, it is a relatively simple problem to introduce a condition where volume is down — or up — by ten or twenty per cent. By making another run through the computer, we can determine what results could be expected under such conditions and begin to concern ourselves with what counteraction or correction would be required to keep the system in balance. The problem of a change in mix is always a difficult one, but if we have properly designed our model and defined our terms, we can measure this sort of impact. By properly breaking down elements, we can segregate those items that are truly affected by mix on a functional basis, and those which remain constant regardless of mix.

Similarly, we were able to measure the effect of manufacturing losses. This, of course, is a complex problem in that it not only results in out-of-pocket losses, but also limits the efficiency of the facilities elements of the business. For example, if losses can be reduced, we can effect not only a direct saving, but also can increase output and, assuming the market can support it, arrive at a higher level of over-all efficiency. By introducing a series of assumptions as to possible loss reductions, we can measure these results and get some indication of the amount we could afford to expend to achieve these results.

Some General Conclusions of the Study

For obvious reasons, I will not go into the specific results of our study. In general, we were able to draw these conclusions:

1. We were not operating one business, but two distinct businesses, tied together by a common technology.
2. In the replacement business, the problem of distribution was of primary importance, to the extent that manufacturing considerations could be subordinated to some degree.
3. In the equipment business, the problem of efficient utilization of the manufacturing facility was of primary importance, to the extent where even certain marketing policies might be subordinated.

From this point on, we were able to erect some new guide posts in re-establishing our objectives and plans for the future.

General Conclusions as to Business Models

What are the general conclusions we can draw from all this? What is the general applicability of such a method of approach? In my opinion, it is not only a very valuable management tool, but, as our business system grows in complexity, it will become an absolute necessity. We have already reached such a degree of specialization of functional development and training that some device is sorely needed to bridge the gap between sales, engineering, manufacturing, and all the other functions; a device that will provide mutual understanding of the common purpose and the interrelationship of functions.

Specifically, the "systems" approach to a business, the development of a model of the business provides the following:

1. *A better understanding of the business: its purpose, its functions, and its meaning.* On the surface, this seems a fairly simple thing. In actuality, it is far from simple, and as we get further away from management and deeper into the "doing" part of the business, the total concept becomes more obscure to individual functions, and sometimes more important to its successful operation. We have a great need for manufacturing to better understand the needs of the marketing function; to appreciate, for instance, that the lowest manufacturing cost is not always the best business policy. We have a great need for engineering to more fully understand the needs of marketing and manufacturing. Certainly we have a need for marketing to understand the requirements of both manufacturing and engineering. Necessarily, any business system is a system of compromises; the problem of management is one of continuously maintaining the system in proper balance so that it performs its total function with maximum efficiency. To do this, it is necessary first to understand exactly what that function is, and second, to understand the contribution that each element makes to the total function both with respect to the total and with respect to all other elements.
2. *An appreciation for the meaningful information in a business system as differentiated from the data in the system.* We all know that in examining a business, there is an immense amount of data available. I believe we are all dimly aware of the fact that the bulk of this data — perhaps 90% or more — has practically no information content. A relatively few considerations fix the pattern for the business; the rest is automatically derived from them.

Let me try to illustrate this point—again on a somewhat over-simplified basis. Within the framework of our long-range plans, once we have set up a sales forecast for a period and an inventory policy, we have, to all intents established the entire pattern of the operation for that period. From this information, we develop a production schedule—automatically. From the production schedule, we develop manning requirements—automatically, and so forth. In other words, in establishing our sales forecast and our inventory policy, we have set into motion a long series of automatic actions, decisions, and limitations. From that point on, assuming that the sequence of events and limitations is understood throughout the operation, there is no real requirement for further information or decision. Things do not happen at random; they happen according to a natural pattern. I strongly suspect that we, as Managers, spend 90% of our time worrying about decisions which are not or should not be matters for decision. We should concentrate our efforts only on those things that are not fixed by pattern; the things that can happen at random or that we can control.

An analogy, to this business of knowing what is and what is not significant from the decision-making standpoint might be found in the automobile. Not too many years ago, we had to make a fairly large number of decisions when we drove a car. We had to advance the spark, pull out the choke, throw out the clutch and start the car. Then we had to put it in gear, engage the clutch, and accelerate to the proper speed. We did all this by sound and feel and it represented an important part of driving a car. Actually, of course, all of these decisions were subsidiary to the general decision that we wanted to move forward. Over the years, we have seen these decisions so recognized and mechanisms built up to remove the necessity for making them. We now make the decision to start the motor by turning a key and to go ahead by putting it in gear and accelerating. The car "knows" when we start the motor, we want it to keep going. If it needs choking, it automatically provides it. If it needs more power, it automatically shifts. These things are no longer subject to decision and, as a practical matter, the car does the job itself a lot better than we used to do it.

The general approach which we are discussing is a means of segregating these different kinds of decisions. The decision to go ahead in a car is important; this we reserve to ourselves. The decision to shift gears is not important; this we do automatically.

As I said before, I believe we, as Managers, operate at about 10% efficiency; 90% of our time is spent in fiddling with shifting gears, choking the motor—sometimes dropping the fuel in the carburetor, when we should be concerned with the next bend coming up in the road. If we can determine what is important—what decisions really affect the business—and what is or should be automatic response, we have some opportunity to do something about it and at least get to 20% efficiency. The first requisite is being able to differentiate between the decisions that are significant and those that are automatic or semi-automatic, and hence, insignificant.

3. *A mechanism for planning and controlling a business system.* The model of the business, in addition to providing a basic understanding of the business and a means of distilling the information content, also provides an important planning vehicle and a control, or at least a feed-back mechanism. Looking first at the problem of planning, we have the opportunity of first determining the areas where decisions are important, and secondly, of measuring the impact of an entire range of decisions quickly and easily. In planning our operations, we often start out with a particular sales goal. We all know that the goal is not going to be met perfectly to the last dollar and cent. It has a margin of error, and part of our job is to minimize that margin of error. Equally important, however, is recognizing what that margin of error may be and determining what will happen (or what should happen) if the full error is actually realized. Suppose our business is relatively stable and we can predict our sales within plus or minus 5% or 10%. How should we plan our operations; on the low side, on the high side, or on the nose? To get an accurate appraisal, we should run out perhaps all three points and determine what the relative risks and rewards are. Similarly, throughout the entire structure we are dealing with a limited number of unknowns. If we fully appreciate what those unknowns are, where and how they affect the business, and, of equal importance, where they do *not* affect the business, and we have a quick, economical means of doing it, we can run a series of plans and from them develop an optimum.

   Equally important, however, is the use of such plans as a measure of performance. Here we introduce the possibility of feedback and control. Having selected a particular course of action, we have the opportunity of continuously measuring each function of the business against that plan. As deviations creep in, as certainly they must (and the deviations are the really important elements of control), we can measure their impact, determine what freedom of action we have, and make the appropriate adjustments to maintain the proper balance throughout the system. In other words, this can become the automatic shift that puts the system in high gear at the right time, or switches to low when the hill gets too steep.

Conclusion

Today we are just beginning to appreciate a few of the possibilities of automating the business of running a busi-

ness. If we carefully examine the system as a system, we find that there are vast areas that are, in the final analysis, mechanistic responses to a relatively few important speculations or decisions. We have tremendous opportunities of ordering our data and our communication system in such a way as to effectively control our individual businesses and to introduce the feed-back systems necessary to that control. The surface is just being scratched, and much remains to be done.

Going back to our automobile analogy, there was a day when the understanding of what went on in a reciprocating engine was very difficult and esoteric. Today, most of us are reasonably familiar with this kind of a system. The designers have developed change after change that has simplified and improved the business of driving a car. Most of the old levers and pedals are gone. Some of us mistrust these developments, but on the whole, they are today practically standard equipment.

In this field, we are at the stage of putting the first few models together. The possibilities are beginning to shape up, but the general understanding of what we are trying to do is still difficult and esoteric. I can fully appreciate it, if what I have had to say above is nonunderstandable. Regardless of that, I would like to convey the thought that exploration of this field—the automation of management—can be a valuable and rewarding pursuit. I, for one, believe that it is inevitable.

Our last thought: In the event that the idea of automation of management is frightening, let me remind you that it is merely a means to an end. Going back to the automobile analogy, the automatic chokes, automatic shifts, power steering, and power brakes, have been a material aid to the drivers with good judgment, but the drivers with bad judgment can still manage to smash their cars up with no trouble at all.

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The MAPI Formula—Estimating Function or Analytic Model

By Harold O. Davidson

Operations Research Office

The stimulus for these remarks is R. B. Orensteen's "Topics on the MAPI Formula" in the November–December 1956 issue of this Journal (1). Orensteen observes (and others will doubtless confirm this) that semantic difficulties appreciably interfere with an understanding of the conceptual basis of the MAPI Formula. By showing a development of the MAPI Formula through the orthodox minimum cost formula, in Part 1 of his paper, he provides a more straightforward approach to the problem than most industrial engineers will find in Terborgh's discussion (2). This is a positive contribution.

Part 2 of the Orensteen Paper contains an excellent demonstration of how obsolescence may be taken into account implicitly in the rate of return or in capital recovery periods or in salvage values to produce essentially the same results as the MAPI Formula. Here again the approach of this paper seems more conducive to a clear insight into the matter than is provided by some previous discussions. Part 2 of this paper also endeavors to answer certain critics of the MAPI Formula and then finally undertakes support of the conclusion that "it is the 'best' approach to equipment analysis currently available." While there is much to be said for Orensteen's appeal to pragmatism in countering the MAPI critics, his answer appears to have been achieved more through an imperfect apprehension of the critics' position than through a demonstration of the fundamental soundness of the MAPI concepts. It is proposed in the following discussion to set up a conceptual framework in which both the MAPI proponents and critics' positions can be clearly defined and the merit of each position be assessed. It is too much to expect that this effort will end all argument, but it is hoped that it may permit further discussions to be carried on to greater advantage.

Estimating Functions and Analytic Models

The provision of a quantitative basis for decisions on equipment replacement is a problem in prediction. Formulas used for making predictions may be categorized generally as "estimating functions." Within this general category of estimating functions there is a special class of estimating functions which we shall call "analytic models." We presently endeavor to define clearly the difference between the special class and the general category of estimating functions. At the moment we must establish the importance of making this distinction by an assertion (to be supported later) that much of the confusion in arguments over the MAPI Formula is due to the fact that critics of the Formula have, for the most part, directed their skepticism to its validity as an analytic model. Orensteen on the other hand pleads that only validity as an estimating function need be established, although he contributes to the confusion by sometimes arguing in behalf of the Formula as though it were an analytic model. We have allowed ourselves to get this much ahead of the argument in order to suggest that an examination of basic concepts will be highly profitable. We return now to the definition of estimating functions and the special class of analytic models.

The general category of estimating functions is perhaps already quite well defined with a statement that it includes all formulas used for predictive purposes. It is not necessary, for a formula to be considered an estimating function, that one be able to demonstrate an analogical correspondence between the formula and physical reality. That is, it is not required that each fundamental characteristic of the actual situation be identifiable with an abstract element of the formula or that relationships between abstractions in the formulas bear any analogical resemblance to relationships between physical elements of the actual situation as we know it.

This point can probably be made clearer by means of an example. Consider the problem of predicting the relative frequency with which 10 or fewer heads will appear when 100 coins are tossed. The familiar Normal distribution can be used as an estimating function in making this prediction, and it is known from experience that if the number of coins is reasonably large the predictions will be very good. Nevertheless, we cannot show a very good analogy between the physical characteristics of the real situation and the Normal integral. We may, for example, pick out an abstract element "x" in the equation which seems to correspond with a number of heads to be expected in tossing a set of coins. However, we see that "x" in the equation is a continuous variable, whereas the number of heads appearing in the physical situation must be a discrete number. The analogical correspondence between formula and reality is indeed not very great.

This same example may be used to define the special class of analytic models that we spoke about earlier, for

the desired prediction on relative frequency can also be obtained by use of the Binomial distribution. There is an important difference, however, in that each abstract element in the Binomial formula can be shown to have close analogical correspondence with an element of the real problem. In the formula we find an "x" that is a discrete variable and "behaves like" the number of heads in the real situation. We also find an "n" that we can relate to the total number of coins in the actual situation. And we find a third quantity "p" which seems to be the probability that any particular coin will come up heads. In this admittedly simple and well-known example we can feel quite confident on a priori grounds that "x" and "n" will behave in the formula as they do in the real physical situation. We would also expect, prior to empirical verification, that "p" will be essentially a constant for all coins as it is presumed to be in the model. Further, we expect that for all practical purposes the value of "p" is 0.5. It is worth observing at this point that certain of the suppositions that have gone into the analytic model can be empirically tested without the necessity of verifying the entire model. We can, for example, test the constancy of "p" and if we should by some chance find it to be appreciably variable from one coin to another the model could be modified accordingly (leading us to adoption of the Poisson *series* instead of the Binomial distribution function). On the other hand there appears to be no way of validating the normal estimating function except by the full-scale empirical investigation; or at least this would be the case if it were not for the familiarity of our illustrative problem—if it were not for the fact that the binomial analytic model has already been verified, and the normal distribution is known to be an estimating function for the binomial distribution.

The Argument on Analytic Model vs Estimating Functions

It should be obvious at this point that the distinction between the general category of estimating functions and the special class of analytic models is not an original contribution of this paper. The concept is, in fact, central to one of the age-old arguments in the art of quantitative prediction. The designers of physical systems have inclined heavily toward the use of analytic models for predictions, whereas the designers of "socio-economic systems" have relied almost exclusively on estimating functions. Engineers and scientists concerned with realm of physical phenomena are as a rule severely skeptical of estimating functions, except where these functions serve as a means of obtaining approximate numerical answers to already validated analytic models (use of the normal distribution as an approximation to the binomial, for example). Among the advantages claimed for analytic models (with or without the auxiliary use of estimating functions to obtain approximate numerical answers) as against estimating functions are:

1. The development of these models promotes insight into the real phenomenon—promotes "know why" as against mere "know how."
2. As a general rule analytic models of highly complex phenomena may be built up piecemeal with each part being validated separately at a relatively modest scale of investigation. Estimating functions on the other hand must usually be validated in their entirety, and frequently can be validated only by a very large scale investigation.
3. Predictions of the behavior of systems not yet constructed can be made with analytic models simply by inserting appropriate values of the fundamental parameters. But since parameters of the estimating function do not have analogical correspondence to the physical situation, predictions for situations other than those on which the estimating function was validated constitute a particularly risky form of extrapolation.
4. Because the analytic model attempts to achieve an abstract analogy with reality there is a requirement for logical rigor which does not exist in the development of estimating functions. It is possible, therefore, for independent investigators to check the logical adequacy of an analytic model before incurring the expense of empirical validation. This type of examination is much more difficult with respect to estimating functions and defective logic more easily escapes detection.

The other side of the argument does not contest merit of analytic models, per se, but simply questions the fruitfulness of this approach in the design of socio-economic systems. The following claims are often made:

1. There are many extremely complex problems for which there is no immediate prospect of obtaining analytic models. The use of estimating functions in these cases is dictated by necessity.
2. The piecemeal development and verification of analytic models for physical systems is rarely applicable in socio-economic systems because interaction effects between major variables are of considerable significance in the latter case although usually negligible in the former.
3. The empirical validation of estimating functions may in fact be simpler and easier than the verification of analytic models. This is so because existing historical data may be adequate for validating an aggregated estimating function whereas the information required to validate a detailed analytic model may necessitate establishment of an expensive data collection and processing system.

While it is clear from the foregoing discussion that there is merit on both sides of the argument, it is also clear that long-range progress in the basic and applied aspects of both physical and social sciences lies in the direction of analytic model development. This trend is especially accented in the case of the Industrial Engineering profession (see, for example, the paper by D. G. Malcolm which appears in the same issue of this Journal as Orensteen's discussion) (3). It is not surprising therefore, that Industrial Engineers are becoming increasingly familiar with the concept of analytic models, or that many of them should have this concept in mind in examining a new technique.

It also appears reasonable that one might take this point of view when it is suggested to him that the new technique will explicitly take obsolescence into account. It seems altogether natural to interpret this as a representa-

tion that certain elements of the formula behave analogously to the phenomena of obsolescence in the real world. It would not matter, however, if we were to advise all the interested parties, "this formula is an estimating function which incorporates certain explicit, but unvalidated, assumptions concerning the nature and effects of obsolescence." With the Industrial Engineering profession exhibiting an actively growing interest in analytic models it is quite proper that all techniques, old and new, be examined from this point of view.

The MAPI Formula as an Analytic Model

In this examination we accept Orensteen's position that it is inconsequential whether assumptions are arrived at by guessing or by some other means. Indeed, the development of most successful analytic models has been characterized by a large share of intuition (i.e. guessing) in the initial phases. With the concept of analytic models in mind, however, it is not possible to agree with Orensteen's position that the question, "How good are the assumptions?," is automatically disposed of by answering the question, "How good are the answers?" It is entirely possible for a formula to give reasonably good answers because of fortuitous compensating effects within a set of poor assumptions; indeed, there have been instances in the history of Industrial Engineering where techniques have evolved through the addition of new assumptions to compensate for the effects of bad initial assumptions (e.g. see discussion of the Barth-Merrick Fatigue Formulas in Chapter 4 of Reference 4). It can be seen therefore that insofar as the "question" pertains to the validity of the MAPI Formula as an analytic model it is Orensteen who begs the question by refusing to consider the validity of its basic assumptions. At the same time it should be clear in the light of previous discussion that while a successful defense of the basic assumptions would go far to establish confidence in the formula, the failure to defend these assumptions does not prejudice Orensteen's position on the usefulness of the formula as an estimating function. Since this does appear to be Orensteen's position, in comparison to that of the critics who seek an analytic model, he could afford an admission that the assumptions are not realistic which is not too difficult to demonstrate in any case.

The most obvious unrealism in the standard assumptions is the supposition that each succeeding improved machine has an operating cost lower, by a constant amount, than that of a new replica of the previous year's machine. It is a logical consequence of this assumption that as the machines are improved year after year, eventually there is developed a machine which has negative operating cost – which is of course absurd. This is not as apparent in Orensteen's paper as it might be, since after explaining the assumption the author incorporates its effect not as a decrease in the operating cost of the improved machine, but as an equivalent operating cost increase for the old machine. While both treatments lead ultimately to the same formula, the former clearly shows the implications of the obsolescence assumption whereas the author's line of development may leave the matter in obscurity for the casual reader.

The assumption of "identical adverse minimums" will also be seen as unrealistic if one examines the operational logic of the argument. Unfortunately, Orensteen's discussion on this particular point leaves the matter no less confused than he found it. His argument reads in part as follows:

> In formula (10) we have determined g for all future challengers to be the same as that of the present challenge, g. The interest rate is to be assumed the same for all future challengers. There remains the adverse minimum and the acquisition cost. Terborgh chooses to fix the adverse minimum by his second standard of assumption. Since he assumes that the adverse minimum of all future challengers is identical with that of the present challenger, it follows that they must likewise have identical acquisition cost.
>
> We are now prepared to answer the question of tautology. The two standard assumptions would be tautological had the acquisition cost been fixed by assumption. Without either an assumption regarding acquisition cost or adverse minimums, the presentation would be incomplete. With this in mind, Terborgh obviously prefers to fix the adverse minimums, thereby also fixing the acquisition costs.

The first sentence of the foregoing passage is not fundamental to the matter at hand, but it does illustrate the imprecise language in this part of the paper. The statement appears to say that the constancy of g is a consequence of formula 10, whereas it is perfectly clear in the preceding parts of the paper that the development of formula 10 follows from a *prior assumption* of the constancy of g. This same neglect of operational logic is manifest in the matter of "fixing" the adverse minimum, as against fixing the acquisition cost. It is interesting that the question which must almost necessarily be faced in developing an analytic model has apparently not occurred to either Terborgh or Orensteen, namely: which is the independent and which the dependent variable? If one takes the point of view that the formula is not an entity in itself, but is intended to have some sort of analogical correspondence with the real world, it is apparent that one cannot in any operationally meaningful sense "fix the adverse minimums, thereby also fixing the acquisitions costs." The adverse minimum is a derived abstract quantity, which emerges as a consequence of the definition of certain independent variables and the relations among them.[1] It is clear therefore that no matter what is *said* about "fixing" adverse minimums the logical operation actually performed here

[1] When there has been a proper sorting out of dependent and independent variables, the question of tautology becomes much simpler than Orensteen finds it. A reasonably careful application of operational logic would also preclude the false inference that "these two standard assumptions would be tautological had the acquisition cost been fixed by assumption". From the definitions of c (acquisition cost) and g given earlier in the paper, it appears that they are independent variables. If these are independent variables, and it would seem difficult to prove that they are otherwise, tautology is impossible.

is an *assumption* that acquisition costs remain constant for all future machines. While this assumption is not necessarily false, purchasing agents would probably find on the basis of their historical experience that it is somewhat unrealistic.

The two assumptions discussed above have been shown to constitute observable deviations from reality. However, the most serious deficiency of the MAPI Formula as an analytic model on which to base "dynamic equipment policy" is its implicit assumption as to the nature of obsolescence. Insofar as the MAPI Formula portrays it, obsolescence consists in the development of new machines which are improved, but "functionally identical" with respect to the old. From the standpoint of, say, a lathe manufacturer looking at his product line this may be a fairly complete description of obsolescence. There are many firms, however, for which this is but one of several kinds of obsolescence that must be taken into account in managing the investment in equipment. A machine may also become obsolete because of development of a new machine which combines its function with that of several other old machines. A machine may also become "effectively" obsolete because the entire process in which it is employed becomes obsolete. Obsolescence of a process may come about not merely because of the development of an improved process, but may also occur when a necessary change in product design dictates the use of a new process. The impact of product design changes on management of the equipment investment is potentially great in any highly competitive consumer goods industry. It can be pointed out, for example, that when the automotive industry switched to all-steel design the woodworking machinery formerly used in this industry suffered a type of obsolescence of which the MAPI concept takes no cognizance. Because this concept of the nature of obsolescence is far more difficult to modify in the MAPI Formula than the assumption of uniformly decreasing cost of improved machines and the assumption of constant acquisition cost for future machines, it appears to be the most serious limitation on the potential usefulness of the MAPI approach as a general analytic model.

The MAPI Formula as an Estimating Function

In the preceding section of the discussion we have sided with those critics who, looking at the MAPI Formula as an analytic model, have found little to praise in it from this point of view. Had this examination encouraged belief that the MAPI Formula might be a good analytic model there would be, a priori, an immediate presumption for reasonably good answers. Failing this test, the ability of the MAPI Formula to produce satisfactory answers as an estimating function comes into consideration as an independent question. Orensteen's demonstration of the equivalence of the MAPI Formula to older methods certainly shows that the answers obtainable by use of the MAPI Formula can be as good as those obtained by these other methods. Moreover it would appear that, as an estimating function, the MAPI Formula is not limited to applications in which obsolescence conforms to comparatively narrow concepts adopted in development of the formula. To rationalize this one abandons the effort, such as Terborgh and Orensteen have made, to give literal interpretation to the factor g and treats it as a purely abstract device which can be manipulated to essentially the same ends as are achieved by varying the interest rate or capital recovery period in orthodox methods. Just how one goes about selecting appropriate values of g when it is regarded simply as an abstract device is not entirely clear, but a basis for the selection could undoubtedly be worked out.

In certain firms it is possible that the problem of managing equipment investment is conveniently handled in terms of the MAPI formulation. It appears doubtful, however, that many persons familiar with conventional methods would find it worth the effort to achieve facility with the conceptual rationalizations and the unique vocabulary of the MAPI approach for the purpose of replacing their established procedures, albeit they might find profit in an examination of the MAPI formula development.

Conclusions

The intent in this discussion has been to avoid taking a categorical partisan stand for or against the MAPI formula; but rather to show the existence of several reasonable points of view and to indicate the positions to which they apparently lead on the basis of the existing evidence. In particular we desire to avoid any suggestion that there should be a general endorsement or rejection of the MAPI formula or similar methodologies, such as Orensteen has recommended. His belief that "if the MAPI Formula is adopted by reason of its support, there will be a contribution to national welfare" appears to be supported more by enthusiasm than by a reasoned demonstration of how national welfare will be enhanced by universal employment of the MAPI formula in preference to leaving the selection of methods in the realm of individual professional or managerial discrimination.

Summarizing

The principle objective of this discussion has been to show that the MAPI Formula may be examined in two different frames of reference, and to suggest that recognition of this difference in possible viewpoints can provide the basis for more profitable discussion. The distinction suggested is between a general category of *estimating functions* which includes all quantitative prediction methods and a more restrictive sub-class of this category, called *analytic models*. When this distinction is made it appears that most fundamental criticisms of the MAPI Formula have to do with its validity as an analytic model. Examination of the MAPI approach indicates that the critics occupy a strong position on this question.

An opposing position has been argued by R. B. Oren-

steen, one of the more lucid expositors and proponents of the MAPI Formula. Examination of Orensteen's position indicates that he dismisses the question of analytical model validity (with an apparent lack of appreciation for its merit) and pleads his case entirely on the validity of the formula as an estimating function. The argument in support of this position is sound, though it does not demonstrate conspicuous superiority of the MAPI Formula to more orthodox methods. An additional argument favoring universal adoption of the MAPI Formula has been offered by Orensteen, but in the absence of support for the contention it appears to have little bearing on the matter.

Striking a balance on the current state of the MAPI Formula debate, it appears that proponents of the Formula can establish a good case for its practical validity as an estimating function whereas critics can point out serious deficiencies as an analytic model.

REFERENCES

(1) Orensteen, R. B., "Topics on the MAPI Formula", *The Journal of Industrial Engineering*, Vol. 7, No. 6, November-December 1956.

(2) Terborgh, George, *Dynamic Equipment Policy*, McGraw-Hill Book Company, New York, 1949.

(3) Malcolm, D. G., "The New Industrial Engineering", *The Journal of Industrial Engineering*, Vol. 7, No. 6, November-December 1956.

(4) Davidson, H. O., *Functions and Bases of Time Standards*, American Institute of Industrial Engineers, Columbus, 1952.

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READER COMMENTS

THE APPARENT CONFUSION EXISTING IN THE RELATIONSHIPS BETWEEN THE FIELDS OF MANAGEMENT AND ENGINEERING

Some of the articles appearing in your *Journal* as well as some appearing in other literature indicate considerable confusion in the character of the relationships between Management and Engineering.

If we expect to have a real profession of engineering, it has to stand on its own feet in attractiveness as a professional career and in financial remuneration. The profession of engineering can never be built on the concept that the purpose of engineering is to provide management personnel. That is a separate and distinct field, also tending to develop towards professional status.

Professional Engineers should be primarily concerned with the advance of the profession, with their service to society through the organization with which they may be associated. Their concern should not be in the development of management. The professional engineer should be essentially a consultant to management. This includes the industrial engineer if he is to be an engineer.

I have seen no real evidence that engineering is the best preparation for management. The fact that a number of engineering graduates (B. S. level) in the past have taken up advanced education in management after completing a Bachelor's program or have gone into general management, does not prove that engineering undergraduate education is the best education for management. Also if some men follow such a pathway, they should not be considered as engineers going into management. The Bachelor's work is essentially preprofessional just as it is for other professions. Such men do not become professional engineers and therefore should not be classified as engineers entering the management field.

Some studies made by *Fortune* showed that the proportion of professional engineers entering top management was no greater than that, for instance, of lawyers entering top management.

Let us keep engineering as engineering and management as management. This lack of distinction leads to the confused thinking about industrial engineering and industrial management.

To be engineering, it must be concerned with economic scientific design based upon the application of mathematics and appropriate sciences. Related to this is research and development leading to design. These are also part of professional engineering practice. Design involves the design of devices, processes, and systems. The industrial engineer needs to be concerned with design if he warrants the title of engineer. It appears to me that he is primarily concerned with the design of productive processes and systems. Involved in this design are machines, materials, and men. The reference to men here does not include the management of men, except in so far as such management produces an effect on the men engaged directly in a productive process. It includes all human effects, affecting the process, but this is all. A comparable situation is the use of mathematics in Electrical Engineering. This use of mathematics does not make the Electrical Engineer a mathematician.

Let engineering be a profession of engineering capable of standing on its own feet and let management be a profession of management separate and distinct from engineering. *R. L. Sweigert, Dean, Graduate Division, Georgia Institute of Technology.*

A CHRONOCYCLEGRAPH IN COLOR

About 35 years ago, just prior to his death, Frank Gilbreth had been working on an instrument which would enable the Motion Study analyst to trace, on a photographic film, the motion paths of an operator's hands. However, it remained more or less of a scientific curio until Miss Anne G. Shaw, of Cheshire, England, reintroduced the technique a few years ago. Recent textbooks on the subject of Motion Study make mention of Miss Shaw's work but apparently very little has been done with the technique in this country.

About a year ago, we negotiated the loan of some equipment for the purpose of photographing and analyzing some "canned" motion sequences which were set up in the Industrial Engineering Laboratory at Northeastern University. The results were so intriguing that we decided to experiment with the device on some short cycle sewing operations at the Malden Knitting Mills in Malden, Massachusetts. The use of a Polaroid Land Camera enabled us to adjust to ideal conditions as we progressed with the study. However, one of the shortcomings of this technique was immediately apparent. During portions of certain cycles the light paths of the two hands became so intertwined that it was impossible to distinguish the path of one hand from that of the other. Also, the machine which we used would alter its pulse frequency whenever the light intensity was increased.

We solved the problem of intertwining motion paths by using a white light for one hand and a red light for the other in conjunction with color photography. Much credit is due to the Electronic Assembly Company of Boston. This company helped us by designing a transistorized circuit which would produce sufficiently bright lights at constant pulse frequency. Using this new instrument we can film up to a half minute cycle under almost normal

factory lighting conditions without blurring in the operator's hands. This is accomplished by making the light intensity high on the instrument and using a high f stop number on the camera.

There is no doubt but that chronocyclegraph techniques, either in black and white or color, will prove invaluable as a relatively inexpensive refined motion study tool. Miss Shaw lists the following ways in which she has found the chronocyclegraph useful: (pp. 2-68 to 2-72, *Industrial Engineering Handbook*, McGraw-Hill Book Co., N. Y., 1956).

1. Recording an unrestricted movement.
2. Analyzing a complex single-purpose movement.
3. The experimental stage of a new method.
4. A check on the training of new operators.
5. A teaching device.

George L. Palken, Professor of Industrial Engineering, Northeastern University and Maurice B. Kaufman, Works Manager, Malden Knitting Mills.

THE RELATIONSHIP BETWEEN HEART RATE AND THE INTENSITY OF WORK FOR SELECTED TASKS, by H. H. Young, *Journal of Industrial Engineering*, November-December, 1956.

Professor Young in his recent article (1) has raised a very old problem as to the place of physiological measurements, such as heart rate, in time and motion study. The present contribution to the discussion is written with recent experience of research at the College of Aeronautics, Cranfield, (2) with fatigue allowances very much in mind, because a basic need in this research was to assess the strain on the worker, and heart rate gives some indication of this strain. Heart rate in the writer's opinion has face validity in such investigations, but can be misleading, and this will now be discussed.

In studying the worker and his job, various aspects of the total worker-job situation are studied, the aspects differing between the scientific disciplines within which the technician works. The physiologist is concerned with aspects of the worker himself which must necessarily be measured (or observed) outside the skin of the worker while he is working. Heart rate, skin temperature, respiration rate and oxygen usage are common measurements of this type, but they must be taken as indicators of internal processes within the worker's skin. What is heart rate used to indicate in Professor Young's experiments, and is this indication reliable? The muscles, in contracting during work, form lactic acid which is then converted back to glycogen by oxygenated blood. The blood comes from the heart, acting as a pump, and the volume and pressure of blood resulting from heart muscle action is controlled by the autonomic nervous system. Heart action is increased by certain chemical levels in the blood resulting from muscle action, but it is also affected by heat and cold and emotion. In a given case we must, therefore, maintain heat and emotional conditions constant but how can the latter be done? To tell a subject to be normal or not worry is a psychological laboratory cliché. We found, using a Muller pulse counter fitted with telemetry, that some subjects' heart rates increased when the observer was present compared with him being in another room. However, changes in blood flow from heart action involve changes both in rate and in stroke volume. Whereas, the former is measured, the latter is not. Stroke volume varies with heart rate and is difficult to obtain under normally expected industrial engineering laboratory conditions. What we are concerned to find in studying fatigue or effort, however, is the blood flow in the muscles themselves, and heart rate does not necessarily bear a direct relationship to it.

In considering different workers doing what is supposed to be the same job, a further difficulty arises because the *actual* job done by the muscles within each worker is different for each worker. The reason for this is that the anatomical structure of each worker is different. Such effects were shown simply during experiments on ironing (3). Again the jobs done require skill (that of muscle coordination), and this can only come from practice during which muscle build-up occurs. Professor Crowden showed very dramatically (4) that a trained man wheeling bricks required only one-third of the excess oxygen required when he was untrained. In a laboratory setting it is difficult to assess the muscular skills involved and so determine when a subject is fully trained.

With trained men there are individual differences in heart reaction to work, and absolute levels of heart rate are not infallible guides (by themselves) in *individual* cases to strain on the body.

The points raised above must be considered on their merits by every experimenter who wishes to use heart rate; and in the writer's case, the answer was thought to be that heart rate did not provide a useful measurement. This does not mean that heart rate is useless but only in the context of the writer's research into one problem in industrial engineering.

Measurements of physiological aspects of worker behavior such as heart rate and metabolic rate may be useful if industrial work involves considerable muscle action. Modern industry does not usually have work which is continuous throughout the day, is *subject to time study* and which is physically arduous under normal temperature conditions or, if it is, which cannot be reduced to an easily tolerated level by motion study. The Cranfield study did not find any arduous and similar jobs on which a useful statistical sample of, say, six workers were engaged within one firm. American industry uses considerably more power per worker than does British industry and the writer doubts therefore the purpose of studying heavy muscular work except for military purposes.

Considerable research into heart rate has been done by Professor E. A. Muller at Dortmund (5). From his studies he found that the most efficient method of carrying out muscular tasks in order to restrict heart rate levels was to make the worker rest after each work cycle. If we recall that the great American, F. W. Taylor (the centenary of whose birth occurred in 1956 and which seemed to be ignored in U. S. A.) obtained the same result with 'Schmidt'

over 75 years ago, then we must question the advance in the practical result although our methods may be more refined.

This brings us to the important practical point that the work to be done must be a first concern. In Professor Young's experiment the important aspect is the actual pumping of fluid which is easily timed—the heart rate aspect does not seem important if one follows an experimental approach (such as that used by Taylor) in a practical case.

In analyzing jobs using heart rate the multi causal system commented on above can obviously be subjected to statistical analysis. In an industrial setting, however, one is concerned with individual cases, not statistical populations, and trade unions could easily show that injustice would result to *individuals* if use were made of *statistical averages* of heart rate. Until industrial engineers receive considerable training in physiology, I suggest a danger exists in practitioners using heart rate in place of more conventional methods. It must be conceded, however, that the work of Muller and Brouha is suggestive that heart rate can be used to demonstrate principles, but it must be considered along with other indices.

REFERENCES

(1) Young, H. H., "The Relationship between Heart Rate and the Intensity of Work for Selected Tasks," *Journal of Industrial Engineering*, Vol. VII, No. 6, page 300, 1956.

(2) Williams, J. A. C., "A New Conceptual Approach in Work Study", *Journal of Industrial Engineering*, Vol. VII, No. 4, page 168, 1956.

(3) Swartz, V. W., "The Human Energy Cost of Certain Household Tasks", State College of Washington, Bulletin No. 282, 1953.

(4) Crowden, G. P., "The Physiological Cost of the Muscular Movements Involved in Barrow Work", I. H. R. B. Report No. 50, London, H. M. S. O., 1928.

(4) Muller, E. A., "The Physiological Basis of Rest Pauses in Heavy Work", *Quarterly Journal Experimental Physiology* 38, 4, 295, 1953.

J. A. C. Williams, Training Branch, National Coal Board, London.

AUTHOR'S COMMENTS

I was pleased to read Mr. Williams' comment on my recent article, and I can heartily agree with many of his observations. Certainly individual differences do have a pronounced effect upon all physiological measurements, as do temperature, humidity, emotional reactions, and others. Likewise, physiological measurements are most valid under situations involving considerable muscular activity. As we look at current trends in industry, we might decide that physical work loads are no longer important. However, while recognizing that the concentration of effort may well be on the measurement of indirect labor operations, I continue to observe many physically-demanding tasks in local industries and feel that we still have need of a better method for evaluating the intensity of human work.

The two experiments reported on in my article indicated that the physical requirements of a task had a far greater effect upon heart rate than individual differences between the subjects studied. However, it must be clearly acknowledged that the experiments were performed under laboratory conditions, using primarily student operators of the same general age group and physical condition.

The speculation that heart rate might be used as a measure of operator pace, for jobs of varying difficulty, was made with cognizance of the need for individual relationships. As Mr. Williams points out, the unions would certainly object to the use of statistical averages of heart rate. Our current research[1] is therefore concerned with the development of effort heart rate regression curves for individuals rather than for a group of subjects. Without going into much detail, a group of 19 students have been individually run through a 1½-hour controlled experiment involving four metronome-timed paces on a control task, and three other different tasks at selected paces. The control task consisted of cranking a loaded dynamometer, and the other three tasks were chosen to involve similar types of muscular activity.

A regression curve for heart rate upon pace was calculated and plotted for each subject's data. Product-moment correlation coefficients were also computed, ranging from 0.008 to 0.98. The "r" values were greater than 0.90 for 7 of the curves and between 0.80 and 0.90 for 5 more of the curves. The data for the remaining 7 subjects was not conclusive, with "r" values of less than 0.80. Likewise, the slopes of the curves differed substantially—indicating the effects of physical condition, etc. upon the differentials between heart rates at increasing paces on the control task. In one case, there was no significant heart rate difference for all four paces.

We are now in the process of projecting each subject's heart rates on the other three tasks to the heart rate-pace regression curve for that particular individual. Thus we are using the control task regression curve for a particular individual to predict the "effective" pace on each of the other three tasks from the measured heart rates, where the prediction curve has a high correlation between heart rate and pace and where the differentials between heart rates for the four paces are substantial. The "effective" pace thus found from the regression curves should be the same, within an acceptable tolerance, for all of the subjects. At this point, the results look quite promising. However, only "good" regression curves are useful as a basis for prediction.

With the use of a heart rate telemetering device, longer periods of observation are possible. Continuous observation of heart rate during the work period may well provide additional information about the work load than is obtained from terminal measurements. We hope to have such a device available for use within the near future.

My thanks to Mr. Williams for his pertinent remarks.

H. H. Young, Associate Professor of Industrial Engineering, Purdue University.

[1] Bachman, J. L. (M. S. Thesis in Process on Heartrate Pace Prediction), Purdue University.

RECENT READABLES

AUTOMATION

"Developing Small Scale Automation." By F. F. White. *Automation*, January, 1957.

For the small plant, as well as for the larger operation whose management wants to approach automation cautiously, the author suggests small scale automation as a modest approach that can be applied to existing machinery and processing techniques and return the moderate capital investment in a short time. After giving several basic criteria for deciding whether to automate at all and for determining how soon small scale automation will pay for itself, the author discusses procedures for automating on a limited scale.

"Three Dangerous Fallacies About Automation." *The Management Review*, published by the American Management Association, Inc., February, 1957.

The large amount of nonsense written and spoken about automation has given credence to three major misconceptions which could seriously impair the success of what is actually a technical, sociological and marketing evolution. These three dangerous fallacies are: (1) Automation is too complex for smaller companies; (2) automation will force technological unemployment; and (3) automation is a technical, not a marketing evolution.

Many people fail to understand the significance of automation because they don't know why it has entered their lives.

Many labor leaders genuinely fear that automation will cut employment, and it is true that it can displace workers temporarily.

The worker isn't the only one who must defeat the automation bogey man. Some management men have their fears, too.

Management must learn more about automation. P. H. Alspach, manager of General Electric's Equipment Development Laboratory, Manufacturing Services, states: "Today, the challenge of automation has shifted from the manufacturing area into the management area." He and a few others like him in industry have a new assignment: selling middle management in their own companies on the need for automation and analyzing how various management job functions will change under its impact.

"Tailoring Automation to Plant Needs." By R. B. Seidel. *Automation*, October, 1956.

Many smaller manufacturers reject automation because the cost of automated machinery is too high for their limited or short run production requirements. But there are different levels of automation, the author points out, and small companies can achieve important cost savings by utilizing the inexpensive, intermediate levels—e.g., automatic gauging devices on conventional machine tools. Another help to the small producer would be the development of highly standardized, low cost automated machines for the limited manufacture of specialized devices.

"Computers as Design Tools." By J. C. White, *Machine Design*, Page 83, January 24, 1957.

Increasing engineering output and engineering quality without increasing the number of engineering personnel involved is a problem presently facing many engineering departments. One possible method for obtaining the required increased engineering output and quality is to use a computer to perform the bulk of routine engineering calculation. Engineers are thus freed of these tasks and have more time for actual creative and productive effort.

"Where Computers Fit in Metalworking." By J. J. Obrzut, *Iron Age*, Page 71, January 17, 1957.

Present uses of computers have barely scratched the surface of their potential. About five years ago, the computers in use were far and few between. Today, there are literally thousands of installations, and the number keeps growing at a fantastic rate. So much so, that the big problem now is in training and staffing new setups. One estimate places the number of analysts, programmers, coders and operators needed within the next 10 years at 150,000 to 200,000.

The application of computers to specific problems is both easier to follow and of more immediate interest to metal working. Use of General Electric's numerical contouring system to general purpose milling machines is a case in point.

The system requires a numerical director or interpolator. Its object is to provide a complete manufacturing process for intricately machined parts. It's continuous path machining automatically controlled from numerical data.

ENGINEERING ECONOMY

"Fastest Way to Figure Whether to Buy That New Machine." By Dr. R. B. Orensteen, *Factory Management and Maintenance*, Page 102, January, 1957.

One of the problems in considering equipment purchases and retirement is to decide how to work with dollar estimates in order to obtain a signal of profitability.

The author has developed an approach to determining profitability which he states to be almost as easy and economical to apply as the simple payoff rule of thumb, yet which retains the accuracy of the more complex techniques such as the compound interest method and the MAPI technique.

The author's approach revolves around a table which lists acquisition and replacement factors for many types of metal working and shop equipment. Each factor sums up, in one figure, many of the estimates and assumptions underlying the MAPI method.

GENERAL

"Humanation." By H. J. Ruttenberg, *Management Record*, Page 389, November, 1956.

Business forecasters are heavily stressing automation as the key to future economic expansion. But Harold Ruttenberg, president of the Stardrill Keystone Company, believes that automation alone will not solve economic problems. He suggests that productivity per man hour will not rise fast enough to take care of our expanding needs unless it is accompanied by "humanation"—which he defines as "The full release of human creativeness of the working and managing forces, voluntarily cooperating with each other . . . through organized programs of joint participation in the productive process." And in order to attain the goals of humanation, Mr. Ruttenberg advocates a basic change in present labor management relations.

"How to Control Plant Noise." *The Iron Age*, Page 51, February 21, 1957.

Growing emphasis on automation is exposing more workers to noisy working conditions.

Medical experts agree that long exposure to noise can and does cause hearing loss.

Two ways the article suggests to tackle the problem:

1. Scout the plant for ways to stop noise at its source.
2. Set up a system of worker hearing examinations.

Aetna Insurance Company found that a noise suppression program in its offices boosted general efficiency 9.2 pct, cut typing errors 29 pct, and machine operators' errors 52 pct. Employee turnover was cut 47 pct.

Aetna estimated that its program brought net savings of $58 per employee in the first year.

"A Practical Application of Uncertainty Calculations to Measured Data." By L. W. Thrasher and R. C. Binder, *Transactions of the ASME*, Page 373, February, 1957.

In order to answer questions as to the reliability of measurements, it is desirable to classify two types of measurements: (a) the multiple sample, and (b) the single sample. The case for multiple sample measurement is well established, whereas the case for single sample has not been established. The author proposes that the tester estimate his error—the uncertainty interval—and give odds that the error would be less than the uncertainty interval if the measurement were repeated a large number of times. A numerical example is presented.

"Engineering the Creative Process." By P. Marvin, *Machine Design*, Page 95, January 10, 1957.

Individual progress is dependent to a very large degree upon ability to inject creativity into daily activities. Yet very little effort is applied to the development of creative ability—an expenditure of effort that holds the promise of sizeable returns.

A profitable starting point for any activity lies in the development of creative ability. This can be accomplished (1) by removing the barriers to creative thinking; (2) by establishing a background for creative thinking; and (3) by approaching problems in a manner designed to bring creative powers into play. All of this amounts to engineering the creative process.

"Productivity and Economic Progress." By J. W. Kendrick, *Challenge*, November, 1956.

The author analyzes the factors—both human and technological—behind our high rate of productivity increase, which, he maintains, has been largely responsible for the remarkable rise in our living standards. Some economists—pointing to momentous technological improvements in the making—predict a strong acceleration in the rate of productivity increase. It is more likely, the author believes, that our productivity will continue to advance at its present high rate, providing a basic measure of the underlying health of our economy.

"Multiple Management Matures: A Case History." By J. C. Baxter, *Personnel Journal*, December, 1956.

Multiple management can be an effective method of stimulating executive development, states the author, supporting his belief with a description of how a successful multiple management set up was gradually established in his own company. Spurred by extensive participation in management problems, the company's junior executives take their own development in hand, helping each other to acquire managerial skills and attitudes.

"A Survey of Human Engineering." By R. S. Barrett, *Machine Design*, Page 75, January 24, 1957.

For a design engineer, the usefulness of human engineering depends upon two considerations. First, human engineering is a new and rapidly growing field which suffers from a lack of information in some areas. Second, some of the fields of human engineering are readily applied by persons without psychological training, while others are not. A designer who wishes to apply human engineering principles should take advantage of the studies that have been made in areas pertinent to his field. This article reviews the subject and outlines the present state of development of the field.

"The Anatomy of Business Leadership." By F. G. Macarow, *The Management Review*, Page 89, February, 1957.

In the past several years, this country has witnessed a great wave of interest in the training of management people, particularly middle management and top line executives.

Executive action is peculiarly the same, whether the organization be church, state, business, social, or family, and whether the product be automobiles, wheat, visas, or public utility services.

Leadership is a skill that can be imparted and passed on. Most individuals can acquire it, if they are willing to devote the necessary time and effort to do so.

The job of an executive is not a lazy man's job. It requires constant application throughout his career. The leader is important in his job, not because of his own production, but only as he leads people toward the accomplishment of their objectives—objectives that must be channeled toward an over all, planned result.

Whether we call this ability administration, leadership, or management, it is one of our country's scarcest commodities and, at the same time, a commodity that will be needed in increasingly greater amounts to meet the demands of our changing times.

"Management by Participation." By Keith Davis, *The Management Review*, Page 69, February, 1957.

Participation is an overworked word in the business environment, but it is a much underworked activity. The idea sounds good to most business men, but they are frequently unsure what to do with it. Some grossly misinterpret what it is, and others are not sure when to apply it or how far to go with it. One reason for all this confusion is that managers have not had much experience with the modern style of participation.

Participation is defined as mental and emotional involvement of a person in a group situation which encourages him to contribute to group goals and share responsibility in them.

Participation offers many advantages. It is valuable in many areas other than job performance, such as working conditions, community relations, and employee benefits; consequently, its use may produce widespread benefits to a company as a whole.

"Fitting Equations to Experimental Data." *Machine Design*, Page 95, January 24, 1957.

Finding an exact analytical relationship for experimental or laboratory data in tabular or curve form can be a demanding and time consuming task. In most cases, particularly when the equation for a given set of data takes the form of a "power" expression, rapidity and accuracy of solution may depend on the experience, knowledge and mental processes of the analyst.

For such analyses, a powerful research tool is provided by a not very widely known branch of mathematics called the *calculus of finite differences*. Based on simple numerical

principles, this graphical mathematical process offers a rapid and accurate method of "equation-fitting." Basic techniques of the method and their application are outlined in this article.

INVENTORY CONTROL

"Once A Month Buying Will Squeeze Tool and Supply Costs." *Factory Management and Maintenance*, Page 109, February, 1957.

Volume manufacturers order product raw materials on a scheduled basis in order to realize the benefits from volume buying, reduced paper work, and fewer outages. Most of these companies, however, order general supplies and tools (cutting tools, maintenance and sanitation supplies, oils, greases, etc.) as they are needed.

At one company, engineers discovered that 80 percent of the dollars spent on general supplies could be predicted, budgeted and therefore scheduled.

The cost and analysis section of the plant makes up a master requisition for each department. It lists code number and description of each item needed by the department and the "budget quantity"—the anticipated needs for the coming month.

"Statistical Inventory Control." By W. F. Hoching, *Industrial Quality Control*, Page 7, January, 1957.

Author's Note: The inventory control plan described in this article is applicable to situations of uncertainty of demand. When demand is known or fixed, for example through the development of monthly schedules or plans whereby the procurement, production, or distribution of the goods is set accordingly; or in the case where it is policy to minimize and control stock outs through expediting effort, this plan does not apply per se. Such planning and expediting actions preclude the free operation of chance occurrences and introduces bias into the data. In Westinghouse we carefully segregate our stores inventory accounts into "planned" or "probability" accounts. The planned are the relatively few accounts having the high dollar volume of issues or sales. Requirements for these are developed and tied directly to specific sales and production forecasts or schedules, and thus represent known demand. The remaining low dollar volume items are the relatively large number of probability accounts which we control through the use of the techniques outlined here.

MATERIALS HANDLING

"Selection of Tractors for Stockpiling Bulk." By J. Radomsky, *Modern Materials Handling*, Page 99, February, 1957.

Costs of handling bulk storage may be greatly reduced through proper selection of earthmoving equipment. The key factors to consider in planning for a new plant or revamping an existing one are equipment capabilities which involve the consideration of quantities handled, frequency and rate of flow, distances involved, grades encountered and operating costs. Evaluation of the various pieces of equipment being considered in light of the factors mentioned will insure optimum handling cost.

"How to Plan Handling for a New Product." By J. C. Downs, *Modern Materials Handling*, Page 89, February, 1957.

For optimum manufacturing and distribution efficiency, there must be a clearcut relationship between design and materials handling.

Material handling engineering is concerned with four main areas of design:

1. Product design
2. Equipment design
3. Facility design
4. Control design

These are all vital if a company is to achieve good material handling performance and reap the benefits available from integrated material handling systems. In order to achieve these benefits, an adequate material handling engineering organization must be established, and must be given equal status with other manufacturing engineering activities. With the organization must go people, and these people should be material handling engineers who are well informed in methods, mechanics, and costs, and are capable of selling and installing their ideas. These people must design the handling program in its four phases.

"What You Should Know About Hand Lift Trucks." *Modern Materials Handling*, Page 113, February, 1957.

The hand lift truck was developed to move large quantities of materials more easily and more efficiently. Its efficiency lies in its versatility and general usefulness. That is why it should not be overlooked when planning an integrated materials handling system or revising a system already in operation.

The hand lift truck can be used where there is only limited operating space. It can go where larger equipment cannot. It can be used, for example, in the unloading of rail cars where doorways or floors will not permit the passage of powered equipment.

It can be used as a supplementary tool. The hand lift truck is a valuable link in putting together an integrated handling system. More efficient short hauls from machine to main aisles, feeding of production lines and the more efficient use of heavier equipment are some of its advantages as a supplementary tool.

QUALITY CONTROL

"The Nature of the Standard Control Chart, and Some of Its Competitors." By E. G. Olds, *Industrial Quality Control*, Page 4, October, 1956.

The control chart is a tool used to guide decisions regarding an industrial process. The fact that there are other methods of using numerical data for this purpose is a sufficient reason why the control chart has competitors.

One way of comparing methods is to use several methods in attacking similar problems and then decide which one works best. Another way to make comparisons is to set up a mathematical model for an industrial process, adopt definitions of control and lack of control, and then apply analytical procedures based on the theoretical foundation. This is the way which is followed in the article.

"Fundamentals of Analysis of Variance." By C. R. Hicks, *Industrial Quality Control*, Page 17, August, 1956.

Basically the analysis of variance technique is just what the name implies—partitioning the variance (i.e. the square of the standard deviation) of an experiment into parts in order to test whether or not certain factors introduced into the design of the experiment actually produce significantly different results in the variable tested. That is, for example, does the mold in which a casting was made affect the porosity of the casting? Does the scale used affect the weight of a vial of medicine? In each case, interest is in testing whether the effect of the factor on the variable measured is significant when compared with the random variation in the process. Hence the F test or variance ratio is used to make such comparisons.

This is the first in a series of three articles by Professor Hicks. Parts II and III appear in subsequent issues.

"Quality Control of Tubular Steel Products." By W. T. Rogers, *Industrial Quality Control*, Page 6, August, 1956.

While this article is primarily concerned with quality control and tubular products made from steel, it is pointed out that the subject matter is applicable to quality control in

basic industry generally and the material presented pertains equally as well to copper, brass, lead, glass, or an end product for customer consumption of any of the large industries which procure their own raw materials and perform all intermediate manufacturing steps.

There are two generally accepted concepts of statistical quality control, one of which is concerned only with acceptance rejection sampling, and the other with control of the entire process which takes in almost the entire field of statistical methods. This second concept is the one that must be embraced in the quality control program of any large industry.

"Sampling Inspection by Variables with No Calculations." By H. Chernoff and C. J. Lieberman, *Industrial Quality Control*, Page 5, January, 1957.

Most industrial applications of acceptance sampling today are by attributes, and will probably continue in this way. Nevertheless, the increase in the use of modern statistical techniques in industry has resulted in the more widespread use of sampling inspection by variables. The disadvantages of sampling inspection by variables are well known. Perhaps the two most important of these are (1) the increased clerical costs of recording the data and making relatively (compared to attributes) difficult computations, and (2) the operating characteristic curves depend heavily on the assumption that the form of the underlying frequency distribution of the quality characteristic is normal. This assumption is often difficult to evaluate.

The purpose of this article is to present a graphical procedure for sampling inspection by variables which involves no computations and which also gives a check on the assumption of normality.

"Total Quality Control." By A. V. Feigenbaum, *Harvard Business Review*, November-December, 1956.

Manufacturers today are finding themselves faced with demands from customers for ever higher quality, while the cost of quality is continuing to rise. As a solution, the author offers a concept he calls "total quality control," based on the principle that the determination both of quality and of quality cost should take place throughout the entire industrial cycle from the design of the product to its sale. Outlining the organization and operation of a "total quality control" program, the author emphasizes that a greater concentration on *preventing* quality failures will result in the substantial reduction of appraisal and failure costs.

SYSTEMS

"We Use Flow Charts." By H. D. Thomas, *Modern Office Procedures*, December, 1956.

Faced with the problem of breaking in a new mechanized payroll system as smoothly as possible, one company applied the technique of flow charting to the revised procedures, with the result that employees learned them much faster. This article describes the new payroll operation and the current use of the flow charts to train new employees and guide supervisors who temporarily substitute for absent clerks.

BOOKS

Quality Control for Plastics Engineers. Edited by L. M. Deming, Reinhold Book Division, 430 Park Avenue, New York 22, New York, 150 pages, $4.95.

This book introduces the subject of statistical quality control to plastics engineers, the molders and fabricators of plastics products and the manufacturers of plastics materials. It refers specifically to examples of application currently used in the plastics industry. Assuming the reader has no previous knowledge of statistical quality control, the subject is developed to enable those responsible for production of plastics products to use the basic statistical procedures in order to achieve the highest possible standards of performance.

A Primer to the Automatic Office, by William Eustis, Automation Management, Inc., Westboro, Massachusetts, 1956, 93 pages, $7.50.

This revised edition of an earlier publication, *The Automatic Office*, is designed as an introduction to the field. It emphasizes the intermediate steps between manual systems and fully automatic systems and describes how conventional machines may be combined with special purpose equipment to service all types and sizes of offices. Included are a number of diagrams as well as case histories of the use of integrated systems in various industries.

Company Investigations of Automatic Data Processing, by Peter B. Laubach, Division of Research, Graduate School of Business Administration, Harvard University, Boston, 1957, 258 pages, $3.00.

A report on the methods used by leading companies in determining their need for data processing equipment. Based on an investigation of some 40 management teams in various industries, the study describes how the teams were selected and organized, how equipment needs were evaluated, and on what terms new equipment was acquired.

Maintenance Engineering Handbook, by L. C. Morrow, Editor, 1528 pages, McGraw-Hill Book Company, New York, $20.00. (This book can be ordered from the *Journal of Industrial Engineering*).

More than 75 experts offer techniques, methods, and procedures to keep production at maximum levels, to control production costs and losses, and to prolong the productive life of plant and related equipment.

The information ranges from the organization and administration of maintenance forces to practical details of maintaining buildings and service equipment, sanitation and housekeeping, and corrosion control.

CONFERENCE EXHIBIT

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Completely automatic positioning of all decimals and all carriage dials is one of the many revolutionary new operating advantages offered by the new Marchant "Deci-Magic", a single keyboard automatic electric calculator.

At the touch of a single key, the "Deci-Magic" automatically sets decimal points in the keyboard and all four dials and automatically positions its carriage in readiness for any type of calculation. All entries to the keyboard are around the selected decimal point. All answers displayed in the carriage dials are automatically pointed off correctly at the conclusion of every calculation.

All clearances of keyboard and dials during and upon completion of a problem are fully automatic, with selective nonclearance for the keyboard and each of the four dials by means of individual "touch set" locks.

The new Marchant "Deci-Magic" has a separate front dial for visual check of individual or constant multipliers. Among many other advantageous features of this highly versatile new Marchant are automatic single entry squaring, automatic half cent round off, automatic accumulation of products and quotients, and grand total accumulation.

(This write-up was received too late to appear in the March-April issue.)

INSTITUTE INTERESTS

CALENDAR

Commencing in the last issue, the Institute Interests section of the *Journal* listed activities throughout the country of interest to the membership. Listings are by dates, and give the name of the activity, the location, and a further source of information for those interested. Considerable advance notice is necessary to have these activities listed in sufficient time to reach the membership.

CALENDAR listings for June and later months appear in this issue and the listings will be retained until copy on any particular event is outdated. Mail all listings to N. K. Rogers, Staff Engineer, Systems and Procedures, Waterman Steamship Company, 61 St. Joseph Street, Mobile, Alabama. Items sent to the *Journal* offices in Atlanta can only be included if received in time to be forwarded to your Institute Interests Editor. Deadline for all listings is the 10th of every odd month in the year. Regularly scheduled chapter meetings will not be listed in the CALENDAR, as meeting places and dates are generally carried elsewhere in the *Journal* on an annual basis.

June

5-14 Motion and Time Study Intensive Course, Department of Industrial Engineering, University College of Washington University, St. Louis, Missouri. Write Washington University, attn: James K. Lahr.

11-14 Annual Cornell University Industrial Engineering Seminars, Cornell University, Ithaca, New York. Write Andrew Schultz, Jr., Department of Industrial and Engineering Administration, Cornell University, Ithaca, New York.

12-14 Seminar on Techniques of Operations Research, Department of Industrial Engineering, Illinois Institute of Technology, Chicago 16, Illinois. Write Paul H. Randolph, Assistant Professor, Department of Industrial Engineering.

July

12-20 Southern Regional Graduate Summer Session in Statistics, Virginia Polytechnic Institute, Blacksburg, Virginia. Write Boyd Harshbarger, Head, Department of Statistics, V. P. I.

ALBUQUERQUE CHAPTER

G. A. Fowler, Vice President Research, 5000, talked on "A Balanced Diet for the Technical Man" at a recent meeting of the Albuquerque area chapter of the American Institute of Industrial Engineers. Presented here, in summary form, are his comments:

"The first major element is salary. The market value of the professional technical man's services has been increasing steadily in recent years due to the increased demands of technology and the limited supply of professional engineers and scientists.

"However, the employer must be careful under the pressure of the present circumstances not to be misled into the belief that this is the main element in the balanced diet.

"Opportunity for professional growth is the second important element in the diet of the professional technical man. A job which provides the opportunity for - or better still, demands - professional growth provides a form of compensation not directly measurable in dollars but worth many dollars in the future career of the individual.

"Fortunately, in the past few years, governmental agencies have set a trend to encourage contractors to publish the results of technical efforts wherever possible. Encouraging also is the fact that an individual can gain a certain amount of recognition in his profession within the classified framework of the nation's technical activity.

"Good communications between the policy making levels of the company and all of its professional employees is a form of local recognition to the professional man. If the company gives the professional employee the freedom to determine his own goals and the freedom to take his own approaches to the solution to the problems within the bands of his assignment, it is recognizing the nature of the professional employee."

CHICAGO CHAPTER

The regular February meeting was held on February 12th at the Western Society of Engineers, 84 E. Randolph Street. After dinner, Vic Short spoke on "Human Engineering", a phrase which he "coined".

On March 8th, we sponsored an All Day Work Measurement and Cost Control Clinic at the Hotel Congress. Phil Carroll, noted author and lecturer on Time Study, Standard Data, and Cost Control, conducted this clinic. Mr. Carroll has written several books and many articles in the management field. Because of the great interest in his books, the Chicago chapter arranged to have them displayed.

On April 9, Dr. Wallace Richards from Lehigh University gave a most informative talk on Work Sampling. Dr. Richards has done a great deal of work in this field, and his experience made him well qualified to conduct this program.

The May meeting was our annual business meeting, which was limited to members only.

CINCINNATI CHAPTER

The February meeting of the Cincinnati Chapter was somewhat different than the preceding meetings.

Dr. Robert A. Kehoe, Director of Industrial Health at the University of Cincinnati, gave a very interesting lecture.

He spoke on the industrial engineer's relation to medicine. This opens an entirely new and undeveloped field. The I.E. could be of great service to the medical profession by gathering and plotting data to be used as statistics.

On March 6, 1957, the Cincinnati Chapter completed its 3rd annual conference at the Hotel Netherland Hilton. The subject, "How To Measure a Fair Days Work", was without question one of the best.

Approximately 85 people attended the conference and the results were most gratifying. Everyone seemed well pleased and will be waiting for the conference of 1958.

On March 27, 1957, the regular monthly meeting started with election of officers. The nominees were without opposition so our officers for 1957 are as follows.

President	Harry Placke
Vice President	Lawrence Jackson
Treasurer	Robert Topis
Secretary	Allen Harding

April 17, 1957, the Cincinnati Chapter planned a plant tour to General Electric Company. Due to the enormous size of this plant the tour was limited to the engine overhaul department only. Since several of our members are employees, this was a very interesting trip.

CLEVELAND CHAPTER

The January meeting of the Cleveland chapter was held Jan. 3rd in the Rose Room of Hotel Cleveland. Warren Alberts spoke

on the highly academic and modern subject, "Industrial Engineering and Operations Research." Alberts, an industrial engineer for United Airlines in Chicago, has done extensive work for his own company as well as federal and military agencies.

To introduce his subject, Alberts gave a brief organizational history of United Air Lines and its industrial engineering make up. The company employs about 20,000 people. There, the industrial engineering department serves as an "internal consulting service" for the entire organization. To perform this service, it is organized into four divisions:

1. Division of work analysis
2. Division of organization planning
3. Division of operations research and applied science
   a. applied mathematics group
   b. quality control & statistics
4. Division of regulations & forms

These divisions are used solely as "services" to the entire company. Accordingly, about 10,000 of their employees are on "standards" and they are thus able to measure and regulate peak periods, down to the date, day, hour and portion thereof.

With Operations Research well established at United Airlines, Mr. Alberts said that it now covers many areas of their organization, including 200 aircraft and 13,000 operating miles. It has provided great depth of understanding for all that have been involved in its use or activity.

Questions pertaining to quality curves, norms, etc., followed this most interesting and informative lecture.

The January chapter meeting was highlighted by two award presentations on the floor. The AIIE Fellow award was presented to Floyd Titler, former president of the Cleveland chapter. In 1951, he was cited a "Fellow" at the National Convention for his work at the Republic Steel Corp. on wage inequities—covering more than 12,000 jobs. Mr. Titler is a registered P. E. trained at Iowa State College and was president of the Cleveland chapter in 1952 & '53.

The second award, a $25.00 savings bond, was presented to Bill Crouse, a Senior at Shaker Heights High School. Bill was the winner of the essay contest judged by Marty Miller and Ed Crow. The title of his essay was "Industrial Engineering as a Career." Russell Rupp, principal of Shaker High, and Mr. Crouse were guests of the chapter at a pre-meeting dinner at the Bronze Room. Both award winners acknowledged their prizes graciously and were applauded by the group.

The February meeting of the Cleveland chapter was held Feb. 7th in the Empire Room of Hotel Cleveland. Roger Clouse discussed the timely topic, "Husband & Wife—an Executive Team." Clouse is Vice President and Secretary of the Federal Reserve Bank, and is active in many local and national banking and welfare organizations.

The speaker said that only in the past 5 years has little been done toward examining the husband & wife as an executive team, and how important the wife is as a partner to the husband. In fact, he proposed that the success of a husband is in direct proportion to the success of the wife as a partner.

The Third Plant Tour took place on Thursday, February 21, at 7:00 p.m. at the Heavy Press Bldg. of the Aluminum Co. of America, 2201 Harvard Ave. in Cleveland. This tour covered forging presses, cutting raw stock, final inspections, and plant facilities necessary to house & maintain this heavy equipment.

On March 28 and 29, the Cleveland chapter sponsored its sixth Annual Spring Conference at the Hotel Cleveland. The theme of the conference was "Industrial Engineering Today—And Tomorrow." The program was packed with informative timely subjects, panel discussions and interesting exhibits. The program included the following sessions:

"New Approaches to Cost Reduction", Robert O. Ferguson, V.P. Methods Engineering Council
"Brainstorming in Industry"
"Statistical Quality Control", Dr. J. N. Berrettoni, Lamson & Sessions Co.
"Machinery Replacement"
"Work Sampling"
"Scheduled Maintenance", R. Harvey, Plant Engineer, Thompson Products, Inc.
"Indirect Labor Standard Data", Mr. Palmer, Whirlpool Corp.
"Flexible Budgets", Robert Heller, Representative
"M.T.M. in Warehousing", J. Petro, Thompson Products, Inc.
"Planning & Installing Data Processing Programs", Paul T. Shirar, Eaton Mfg. Co.
"Memo Motion in Plant Equipment & Tool Analysis", Glen D. Wolfe, A. O. Smith Corp.
"Financial Planning & Control", N.A.C.A. Representative
"Mathematics in Management"
"Operations Research"
"Using & Teaching New Techniques"
"Linear Programming"

DAYTON CHAPTER

In keeping with our policy of presenting programs of current and vital concern to the industrial engineer, the February session concerned communications, presented by Dr. Thomas H. Dudgeon, Nationwide Insurance, Columbus, Ohio.

Communications in an organization, or the flow of information, is rapidly becoming recognized as having a significant effect on operational efficiency—communicating ideas and facts, between individuals, upward and downward in the organization are examples of the scope that this field of inquiry involves. Dr. Dudgeon, a consultant in this field, presented a basic concept of communications, including how we do, and how we don't, communicate, and the barriers to communication. He touched on the development of information theory as one approach to this field.

The March meeting dealt with a topic of direct concern to the industrial engineer, "The New Look in Materials Handling", presented by Mr. E. Ralph Sims, Industrial Engineer for Alden E. Stilson & Assoc., Consulting Engineers, Columbus, Ohio.

The purpose of this session was to inform the industrial engineer of the basic shift in attitude toward a systems approach to materials handling and effect this shift is having on the factors involved in materials handling problems. For example, this systems approach in many industries is broadening the scope of the materials handling problem beyond in plant improvement to include the marketing and distribution function as well as product design considerations. This trend, caused by economic pressures and the high potential savings, also has its impact on the materials handling problem in production planning, equipment and means for measuring and analyzing.

LOUISVILLE CHAPTER

For our December meeting, members and guests of the American Society for Quality Control and AIIE met jointly at the American Standard plant. After a delicious roast beef dinner in the cafeteria, we were taken through the plant to view the brass foundry and enameling operations.

Later in the evening all hands gathered in the auditorium to hear a talk presented by Mr. Edward M. Schrock, Quality Control Engineer with American Standard. His subject was "How to Organize an Effective Quality Control Program."

At the January meeting, Dr. Gerald Nadler, Head, Dept. of Industrial Engineering, Washington University, St. Louis, Mo., spoke on "New Horizons in Time Study."

Dr. Nadler identified some new developments or new horizons in work measurement, which were emphasized as being an important and permanent area of time study.

1. Use of *Statistics* in estimating and controlling delays.

2. New concept of *Regarding Human Beings as People* instead of machines.

3. *Timing* in relation to automatic, physiological, and heart rate measurements.

4. Use of *Electronics* in time study. Dr. Nadler concentrated on the future of Electronics and the benefits to be derived from its usage.

MIDDLE-TENNESSEE CHAPTER

Members of the Middle Tennessee chapter, AIIE, took part in American Institute of Industrial Engineers and Society for the Advancement of Management programs at Nashville and Knoxville the second week in February.

Five members of the chapter attended a dinner meeting of the Nashville chapter, Society for the Advancement of Management, at the Hermitage Hotel. Speaker for the session was Phil Carroll, Maplewood, N. J., professional engineer and vice president of the Northeastern Region, AIIE. His topic was "How to Sell Your Ideas."

Five chapter members also attended the fourth annual conference of the Southeastern Region, AIIE, at the University of Tennessee Student Center, Knoxville. The conference, sponsored by the East Tennessee chapter, AIIE, and the U T student chapter featured talks on "Industrial Engineering Control Tools."

PHILADELPHIA CHAPTER

Dr. Harold W. Kuhn, Associate Professor of Mathematics, Bryn Mawr College, was the speaker at the January meeting. The subject of his talk was "Illustrations of Linear Programming." Dr. Kuhn was a guest speaker on Linear Programming at the 7th Annual A.I.I.E. Conference which was held in Washington, D. C. He is the author of a new computational method for assignment and transportation problems and a co author of the fundamental duality theorem of linear programming.

Dr. Kuhn used simple algebra and the above theorem in presenting the solution of a hypothetical transportation problem. The unknowns in the problem were reduced to two variables for graphic presentation. This permitted ready determination of the solutions at the corner points. In theory any linear program could be solved by calculating the values of the functions at the corner points. However, in a real problem this would not be practical because of the number of variables involved. Nevertheless the most successful computational routines for solving linear programming problems are based on computing a sequence of corner points so as to improve the value of the linear function at each step.

The speaker at the February meeting was Mr. Joseph J. Toyzer, Manager, Manufacturing Engineering Administration, RCA Victor Television Division, Radio Corporation of America. Mr. Toyzer spoke on "Automation and the Industrial Engineer." In his talk Mr. Toyzer stated that automation has been with us in one form or another since the beginning of mankind. However, the basic difference is that automation is being used today to replace some of the decision making functions as well as to increase productivity. Automation is not an end in itself. It is a tool which the Industrial Engineer may use to increase the production of goods and services.

Mr. Toyzer stated that labor's fear of automation is groundless. Historically it has been shown that technological advancement does not displace workers and create unemployment. In fact, more automation will be required if industry is to meet the expected labor shortage in the next 20 years. Among the benefits from automation will be greater productivity, more purchasing power, higher standard of living, and more leisure time.

The Philadelphia Chapter sponsored a series of four seminars on Linear Programming and work sampling. Meetings were held from 7 to 9 p.m. on April 24, May 1, 9, and 22 at the Atlantic Refining Company, 260 South Broad Street, Philadelphia. The sessions were designed to cover both the fundamentals and case applications in these areas and were open to members of the A.I.I.E. and other related technical societies. A $2.50 registration fee was charged to underwrite the publicity costs.

TULSA CHAPTER

At its February meeting, the Tulsa Chapter had a panel discussion, "Organizing for Electronic Data Processing" following dinner at the University of Tulsa Student Activities Building. It promoted some lively discussion, led by four men from Douglas Aircraft Company. This panel explained how Douglas planned and installed their EDP system. They then answered questions from the group and gave suggestions on organizing such a program. The four panel members were:

Mr. H. W. Cleveland, Manufacturing Control Manager and EDP Project Director
Mr. C. H. Hart, Manager, Factory Tab and EDP
Mr. W. P. Ingle, Administrative System Analyst
Mr. R. N. McKirahan, Manufacturing Control Representative

The March meeting program was, "The Union's View of Right to Work Laws." The speaker, Mr. E. R. Burns, is president of the Oklahoma State C.I.O. He has a long and illustrious background in labor union leadership, having held many important positions. He is also currently a Commissioner of the Oklahoma Unemployment Commission. Mr. Burns put his views in cogent terms and a very interesting manner. They evoked a great deal of spirited discussion from the engineers present, who are all on the other side of the fence from Mr. Burns. In all, this was one of our most interesting meetings and also one of our best attended.

WASHINGTON, D. C. CHAPTER

The Washington, D. C. Chapter meets on the second Tuesday of each month beginning with September through May at the Perpetual Building Association Building Auditorium, (11th. & E. Streets, N.W. at 8:00 P.M.)

The Chapter's 1956-57 program began with an excellent presentation by Chapter Member, Stephen Arthur Derry, (President, The Derry Engineers, Louisville, Kentucky). Mr. Derry's topic was "The Industrial Engineer Looks at Automation". His presentation invoked some fruitful thoughts on the Industrial Engineer's role in tomorrow's industry. He pointed out how the philosophy of today's concept of "Standards" will be tomorrow's industrial engineers dream. Whereas, the "Leveling" factors in today's method of setting production standards will no longer exist in setting standards for an automated plant. He stressed the new look on "Quality Control" techniques. He touched upon the need for educational institutions to realign the industrial engineering curriculum to meet the needs for industrial engineers' role in automated plants. He pointed out the Industrial Engineer must have more training in Mathematics, Physical Sciences and above all trained "How to Think a Problem Through".

Mr. Dave Savage, Senior Engineer in charge of Univac Programs, Remington Rand Corporation was the speaker for the October meeting. Mr. Savage presented a paper on Industry and Government Uses of Computers. He touched upon how computers were used by industrial engineers in solving problems in Production Control, Inventory Control and setting of standards. He outlined computers role in solving problems in the aircraft industry.

Chapter Member, Lt. Leo M. Kornfeld, USN, was the speaker for the November meeting. Lt. Kornfeld covered in detail how the Navy set standards on typing and clerical work. He compared the method with the techniques used by M.T.M., Time Study, Yale & Towne, Ratio Delay. He outlined how standards were being applied to warehouse operations and public works maintenance areas.

The December Meeting was devoted to the Chapter's Annual (Semi Annual) Business and social meeting. The President and Chapter Secretary cleared all accumulated matters originating from National Headquarters, and at Chapter Level. Among the

committees appointed was the Program Committee. This committee headed by Stephen Arthur Derry and assisted by Noram Kobert as Vice Chairman and William Powell, Crans Cohen, and Edward Pierce as committee members, was assigned the task of preparing the 1957 chapter program from January, 1957 through December, 1957.

Chapter Member, Nelson P. Greller, (President, Nelson P. Greller & Associates, Washington, D. C.) presented a paper on "High Speed Remote Controlled Package Sorting Methods". Mr. Greller with the use of charts, sketches, movie and demonstrations, plus a staff of assistants, presented an interesting detailed description of the electronic sorting machine and how it operated. Mr. Greller and his staff had created the machine, designed it, developed it, and installed it in the Baltimore Post Office.

The electronic Sorter commonly referred to by post office employees as the "Greller System" is capable of sorting and diverting parcel post packages of any legal size and shape at the rate of 12,000 an hour. The memory device can take information on as many as 60 packages to be distributed to some 70 stations or more. The device measures its own package length. All the operator must do is to punch a key, which designates where the package is to be dropped off the belt. The packages pass by the viewer's eye on the belt and from there on the system is 100% automatic. The package is delivered, automatically, to the station which the punched key designated.

Mr. J. J. Saunders, Martin Company, was the guest speaker for the February Meeting. Mr. Saunders topic was, Aireraft Materials from Research to the Flying Vehicles". The many problems involved in producing an airbound vehicle were covered. He pointed out the industrial engineer's part in coordinating the various operations from research, test, design, and construction. He also covered the industrial engineer's role on matters pertaining to money, manpower and materials planning for guided missiles.

The subject matter for the March meeting was a panel discussion on, "Why It Is Important for Engineers to Qualify as Registered Professional Engineers".

The panel was moderated by:

Mr. Oscar H. Beasley, PE, Former Chairman, Washington, D. C. Board of Registration for Professional Engineers, Currently President, Washington, D. C. Chapter, National Society of Professional Engineers, & President, Washington Society for Professional Engineers.

Panel Members and their topics, listed in order of appearance were:

1 Paul H. Robbins, Executive Director, National Society of Professional Engineers, Washington, D. C. Topic: "The Importance of The Professional Engineer to Industry and all Levels of Government".

2 John J. Rockefeller, Deputy for Maintenance, Office of the Special Assistant to the Secretary on Installations, U. S. Air Force, Washington, D. C. His topic was: "What Government Offers To The Registered Engineer".

3 M. N. Wilberding, President, Wilberding Engineering Company, Currently Chairman, Board of Registration for Professional Engineers, Washington, D. C., Past President, Washington Society of Professional Engineers. His topic: "How Applications for Registration are Processed".

4 Stephen Arthur Derry, Registered Professional Industrial Engineer, Active in National AIIE affairs and Member of D. C. Chapter, AIIE, President, The Derry Engineers, Louisville, Kentucky. His topic: "What Registration Means to the Industrial Engineer".

WINSTON-SALEM CHAPTER

One of the most successful meetings of our organization's history was held on November 27, 1956, when 174 members and guests representing 16 varied industries attended a dinner meeting to hear Miss Bonnie B. Small, Department Chief of Statistical Process Quality Control, Western Electric Company, Allentown, Pennsylvania Plant. She spoke on "Quality Control for the Engineer" which created considerable interest as indicated by the questions asked the speaker concerning specific applications of quality control processes presented.

Our most successful Motion and Time Study Conference was held January 17 and 18 at the Hotel Robert E. Lee, Winston-Salem. Approximately 250 Industrial and Management Engineers representing 39 companies and 3 colleges attended. The annual conference is under the joint sponsorship of the Winston-Salem Chapter of AIIE and the Greensboro Chapter of the Society for Advancement of Management. It is open to members, student members and non-members interested in exchanging views on the latest developments and applications in the field of industrial and management engineering.

The conference opened January 17 with an informal evening fellowship meeting to give the conferees an opportunity to become acquainted. The all-day program of lectures and discussions was held January 18 with five distinguished industrial and professional leaders as principal speakers. Mr. C. W. Reynolds, Assistant Works Manager, Western Electric Company, Winston-Salem, opened the program extending a welcome to the conferees. William J. Brock, Jr., President of the Winston-Salem Chapter of AIIE, presided over the morning session and C. Aubrey Tingen, President of the Greensboro Chapter of S. A. M. presided over the afternoon meeting.

The morning speakers were Robert S. Rice, Industrial Production Editor, "Factory Management and Maintenance" magazine, published by McGraw-Hill Publishing Company, New York, past president of the Pittsburgh Chapter of AIIE and past vice-president, Northeastern Region of AIIE, who spoke on "Methods Engineering and Automation" and Dr. Robert N. Lehrer, Professor of Industrial Engineering, Georgia Institute of Technology, Atlanta, Georgia, and Editor-in-Chief of "The Journal of Industrial Engineering" who spoke on "Work Sampling." The afternoon speakers were Mr. Ralph H. Landes, Assistant Superintendent, Engineering Standards, Hawthorne Works, Western Electric Company, Chicago, co-author of "Occupational Rating" and originator of "National Time and Motion Study Clinic" who spoke on "Products and By-Products of Time and Motion Study" and Mr. Bruno A. Moski, Director of Industrial Engineering at Yale Materials Handling Division of the Yale Towne Manufacturing Company, Philadelphia, Vice-President of the Middle Atlantic Region and President of the Philadelphia Chapter of S. A. M., who spoke on "Auditing and Maintaining a Wage Incentive Installation." Mr. R. W. Grupenhof, National Director of the Greensboro Chapter of S. A. M., presided over the evening session. The evening speaker was Mr. Matthew A. Payne, General Manager, Lubrizol of Canada, Ltd., Niagara, Ontario, past president of AIIE and now Director of the Institute's chapter organization and extension and a member of the Long Range Planning Committee and the committee on organization, who spoke on "The Industrial Engineer in Small Plant Operations."

We had the pleasure of having Mr. Howard P. Emerson, President of AIIE, Professor and Head of the Industrial Engineering Department, University of Tennessee, Knoxville, to speak at our February meeting. He spoke on "New Developments in Industrial Engineering." He also presented the organizational structure and functions of the various committees of the national level of AIIE. On March 1 a delegation of our members attended the presentation of the charter and installation of officers of the newly formed Eastern North Carolina Chapter of AIIE in Raleigh.

Our chapter is continuing to strive for a more diversified program of speakers and activities to increase our membership from approximately 70 members and gain a greater representation of the many industries located in this area.

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